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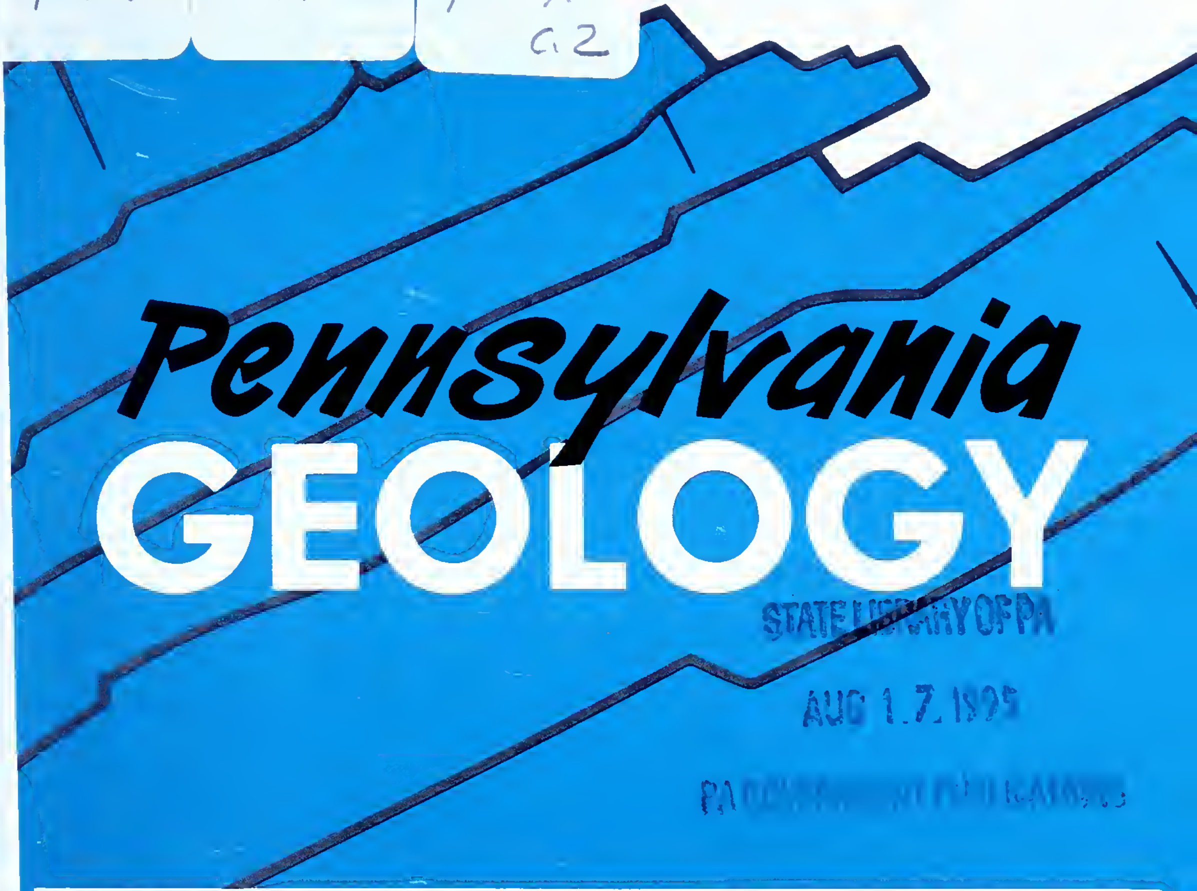

Pennsylvania GEOLOGY

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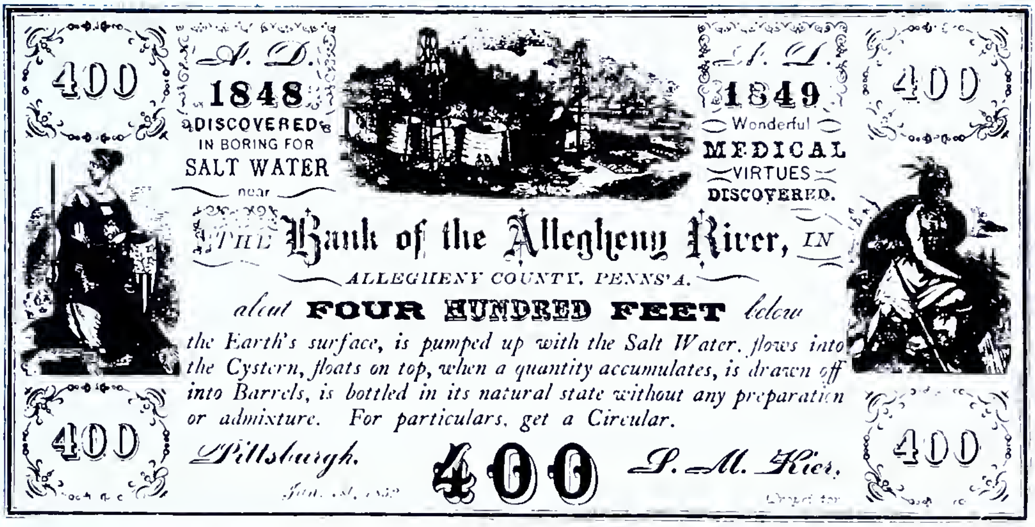

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CONTENTS

Geology, trespass, and safety 1
The “banana” mine—key to understanding the origin of the thick Luthersburg coal in Elk County 2
Yo-ho-ho and a bottle of unrefined complex liquid hydrocarbons 9
Announcements 13
New releases 15

ON THE COVER

The front of one of Samuel M. Kier’s advertising circulars, published to resemble a bank note, that promised his crude oil as nature’s panacea (see article on page 9). Reproduced from Derrick Publishing Company, 1898, p. 948.

PENNSYLVANIA GEOLOGY

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VOL. 26, NO. 1 **SPRING 1995**

STATE GEOLOGIST'S EDITORIAL

Geology, Trespass, and Safety

From time to time, we publish in this journal the locations of outstanding sites where geologic features may be observed or where geologic materials may be collected. These sites may feature examples of local geology, abundant or unusual fossils or minerals, or they may be places where students and others can observe and learn about geology. *However, publication of locations in our journal does not grant permission to visit these sites!* All described sites are located on privately owned property or property that is managed for the public. It is the personal responsibility of anyone who wishes to visit these sites to obtain permission before entry. This is more than common courtesy; it is also a legal requirement.

Recently we were contacted by Pennsylvania officials of Conrail who are concerned about trespass on their property, in particular, along their transportation rights-of-way. These officials asked us to inform our readers of their concerns (see also fossil locality sidebar on page 14). Conrail estimates that during the past year, more than 1,000 people (50 in Pennsylvania) were killed or injured along its tracks in the United States, primarily while trespassing.

In Pennsylvania, Conrail officials report that they have encountered groups of geologists, principally from academic institutions, who have trespassed on their property and who have used the explanation that "the locality description was published in [X, Y, or Z] Journal." This explanation is patently not acceptable, and, if used further, will only result in total withdrawal from all persons of access to important teaching and learning sites.

It is, and has been, the policy of the Bureau of Topographic and Geologic Survey that all staff members should seek permission for entry onto private property for the purpose of geologic investigations. We strongly urge that all geologists, whether professional or amateur, follow the same policy. While at times this may be onerous and may even result in refusal of entry, the safety and legal integrity of all geologists is more important than is the possibility of physical harm or arrest if this recommendation is not followed. In particular, academic faculty should rigorously follow this policy, both as an example to students of proper legal behavior, and as a basic precautionary safety measure.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

THE “BANANA” MINE—Key to Understanding the Origin of the Thick Luthersburg Coal in Elk County

by Clifford H. Dodge
Pennsylvania Geological Survey

INTRODUCTION. “They once deep mined coal here, 10 feet thick, almost directly under our feet.” Little did I realize the significance of this offhand remark by an old-timer back in 1984. When approached by this individual, I was measuring a section and sampling coal in an active strip mine in southeastern Elk County, as part of the Pennsylvania Geological Survey’s continuing program of collecting basic data on the geology and coal quality of the bituminous coal fields of Pennsylvania (see back cover). Although naturally skeptical about unsubstantiated claims of occurrences of unusually thick coal (i.e., greater than about 6 feet in this part of the state), I felt that the old-timer was sincere. I smiled and nodded and recorded his comments in my notes. After thanking him for the information, I returned to my investigation of the strip mine. In time, I put the conversation out of my mind.

The following year, I began a comprehensive geologic mapping study of the coal measures of Elk County. Situated in rural north-central Pennsylvania, Elk County had historically received relatively little attention from government geologists, owing to limited staff and higher priorities elsewhere, and thus had been one of the least studied coal-producing regions in the Main Bituminous coal field (see back cover). However, as part of an ongoing series of county coal-resource investigations, my recent work has yielded much new information on the coal geology of the region. As expected, the geology of Elk County is full of surprises. Particularly noteworthy are aspects of an unusual and seemingly enigmatic coal, the Luthersburg.

REGIONAL STRATIGRAPHY. The type area of the Luthersburg coal is in northwestern Clearfield County, to the south of Elk (back cover). Named for the town of Luthersburg, the coal was first described by Edmunds and Berg (1971); regional aspects of the Luthersburg coal were later discussed by Dodge (1992).

The Luthersburg coal is stratigraphically above the Middle Kittanning rider coal and Washingtonville marine shale and below the Johnstown freshwater limestone and Upper Kittanning coal (Figure 1). In context, Luthersburg is a generic term for coals found at this stratigraphic horizon, toward the middle of the Allegheny Formation (Middle Pennsylvanian), that may or may not be genetically related to the coal at the type area.

The Luthersburg coal interval in western Pennsylvania represents depositional environments marking the transition from dominantly lower-delta-plain to upper-delta-plain sedimentation that occurred during a time of rapid westward progradation, base-level drop, and extensive development of sandy channel belts, which, though absent in Elk County, are collectively known as the Upper Worthington sandstone (Dodge, 1992).

CHARACTERISTICS OF THE LUTHERSBURG IN ELK COUNTY. The Luthersburg coal or its horizon in Elk County is confined to the southern areas, where it is preserved in the deeper parts of the Cowanesque and Caledonia synclinal basins (Figure 2). The Luthersburg coal interval, extending from the base of the coal or its underclay to the base of the Johnstown limestone, is seldom exposed. Consequently, information on the geology of the interval is derived mostly from drillers' records of borehole cores and cuttings, supplemented with data from several former underground and surface mines. Key beds used to identify and correlate the Luthersburg coal include the underlying Lower Kittanning coal and overlying Johnstown limestone and Upper Kittanning coal.

Throughout southern Elk County, the Luthersburg interval is characterized by scattered, isolated lenses of banded coal within an overall coarsening-upward clastic sequence composed largely of shale and siltstone. Underclay is generally poorly developed or absent, particularly where the coal is thick. Sandstone is uncommon. The consistent character of the Luthersburg interval in Elk County suggests that the coal occurrences are genetically related.

The Luthersburg coal is low to moderate in ash, moderate to high in sulfur, and free of partings. It is commonly thin but remarkably thick in a few places. As much as 9.2 feet of coal has been reported by drillers (Figure 2)! This was intriguing because coals of the Allegheny Formation are seldom so thick. I began to think back to the conversation I had had with the old-timer; could this be the same coal seam he had mentioned? It soon became evident that it was.

Because of the limited spatial resolution of the drill-hole data, more detailed information was required to better understand the mode of occurrence of the coal. This was provided by a crucial deep-mine map that accurately portrays the three-dimensional geometry (shape)

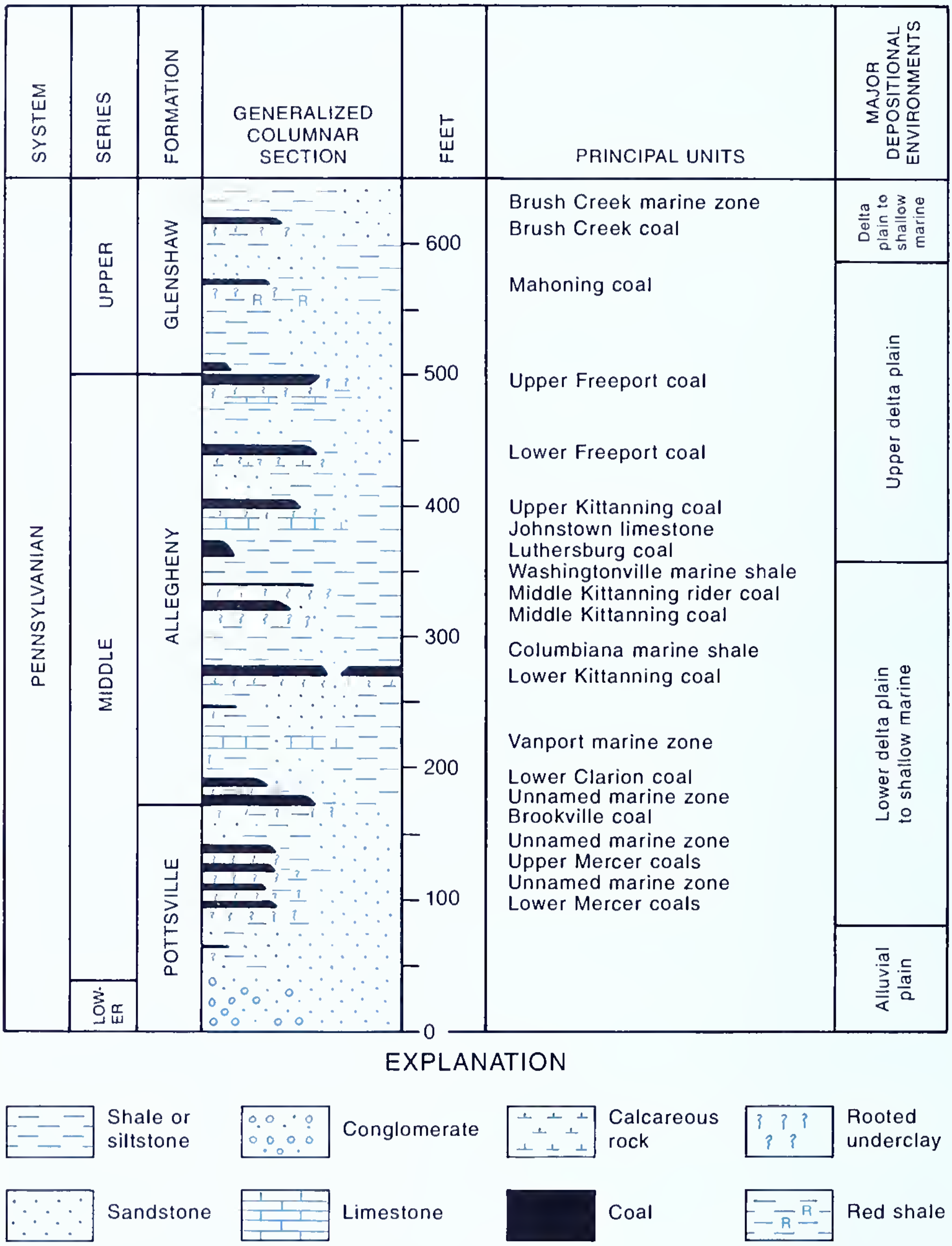

Figure 1. Stratigraphic column of coal measures in Elk County. The thickness of several units in the section is exaggerated for clarity.

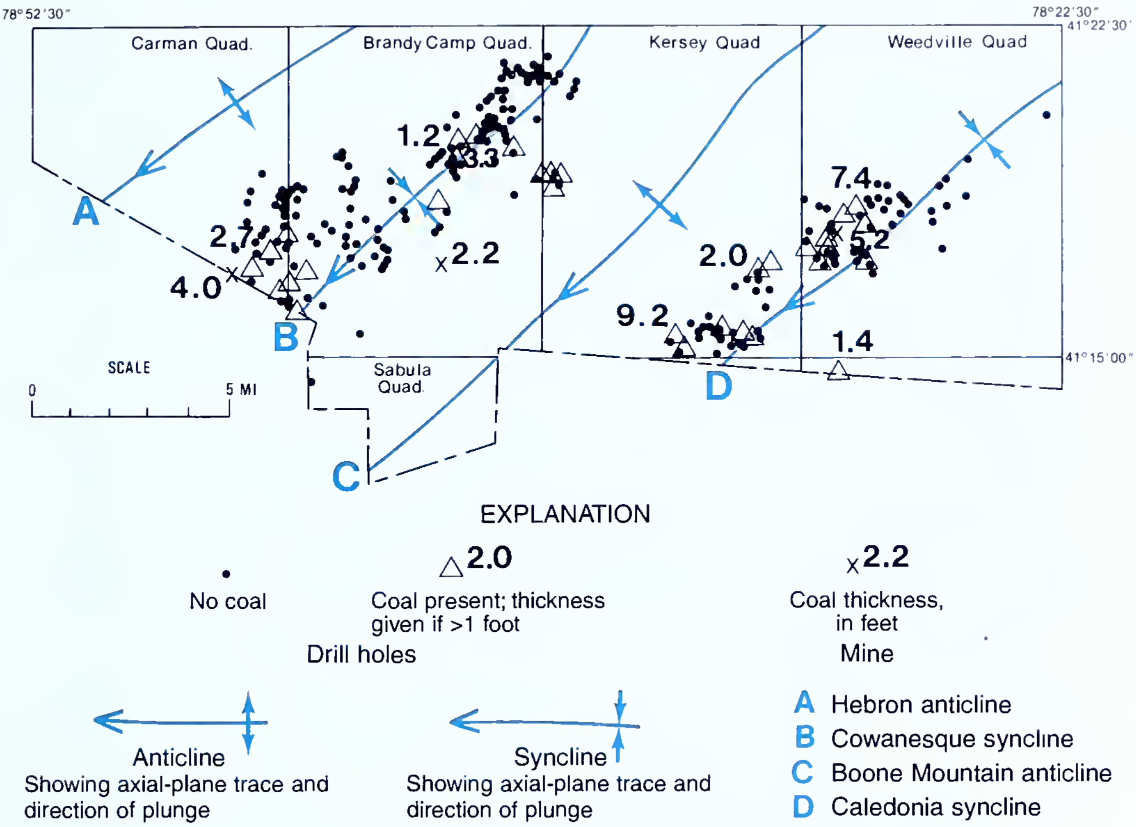

Figure 2. Location of fold axes and distribution of data points for the Luthersburg coal, southern Elk County.

of the coal body. The map strongly suggests that the coal in the mine was deposited as peat in an abandoned stream channel.

CALEDONIA NO. 13 OR "BANANA" MINE. The deep-mine map was prepared by New Shawmut Mining Company for the Caledonia (or Hand) No. 13 mine, which was operated by the Micale family from 1949 to 1966. However, small-scale mining had occurred here intermittently prior to this time, beginning as early as the 1840's. The now abandoned No. 13 mine is located in southeastern Elk County, toward the western edge of the Weedville 7.5-minute quadrangle, about 1.5 miles north-northwest of Weedville near the head of Caledonia Hollow (Figure 3). From the location and character of the mine, it was readily apparent that this was the very one alluded to years earlier by the gentleman I had met near Mount Zion crossroads!

Appropriately nicknamed the "banana" mine, the Caledonia No. 13 is elongate and arcuate shaped, and trends northeast to south over a distance of 1.5 miles (Figure 3). The maximum width of the mine is about 450 feet. Subsurface control prior to mining is indicated by the drill-hole locations. (No exploratory drilling was done during or in advance of mining.) A drill-hole spacing of less than 200 feet would be required to resolve such narrow, elongate bodies. If not for a fortuitous borehole location and natural exposure in Caledonia Hollow, the coal worked in the "banana" mine would probably still remain undetected.

Coal isopachs for the "banana" mine and vicinity are shown in Figure 3. Where mined, the coal ranges in thickness from about 3 to 9 feet and is reported to reach 13 feet locally toward the northern end of the mine. Transverse sections through the mine are lenticular or U-shaped. The mine floor rises toward the edge of the workings by about 5 to 10 feet; the level of the roof remains nearly constant (Lewis Burch, 1992, oral communication). Coal is thickest along the thalweg, or line of maximum depth of the paleochannel. The coal abruptly pinches out to the east and west a short distance beyond the limits of mining and is replaced laterally by dark shale or silt-

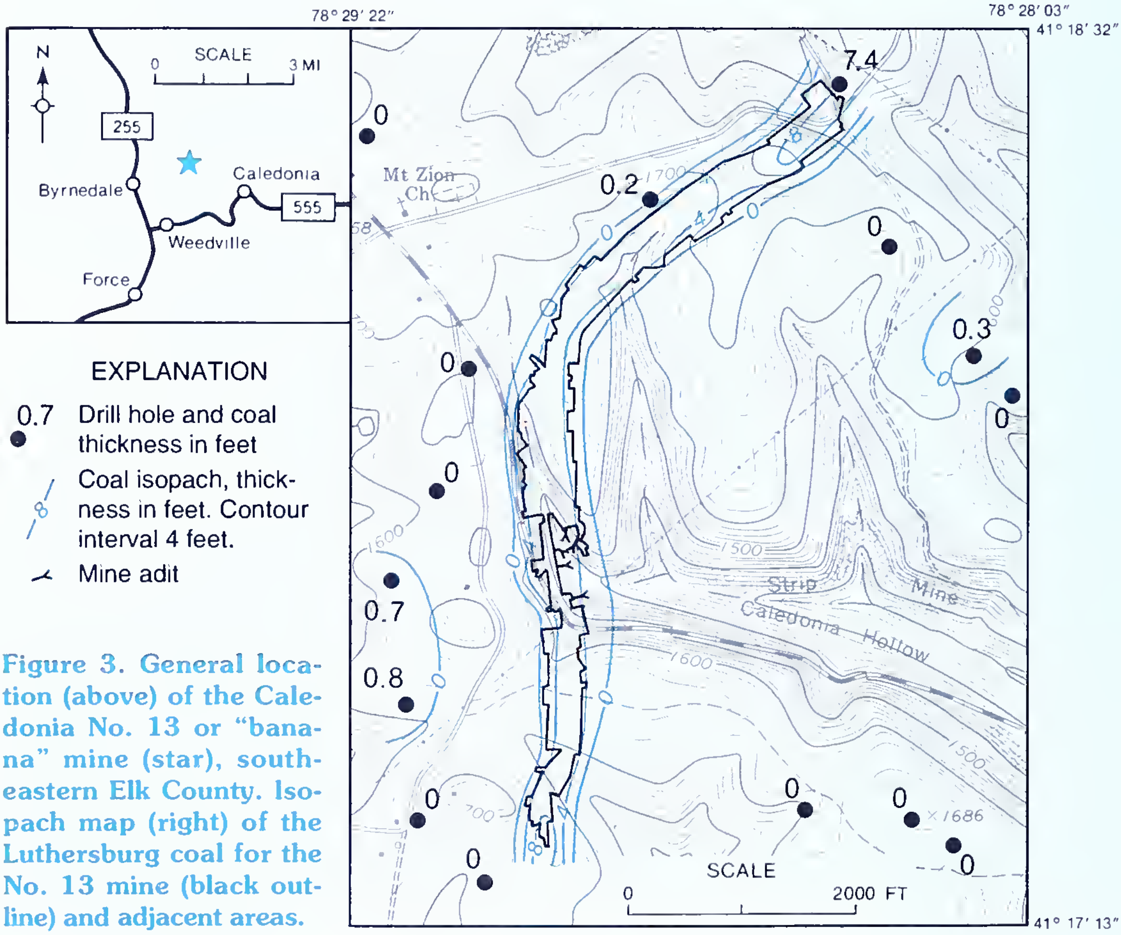

Figure 3. General location (above) of the Caledonia No. 13 or "banana" mine (star), southeastern Elk County. Isopach map (right) of the Luthersburg coal for the No. 13 mine (black outline) and adjacent areas.

stone. Within the mine, the coal is reported to be overlain by light claystone or siltstone and underlain by hard dark shale and perhaps some underclay locally (Lewis Burch, 1992, oral communication). As is typical for channel-fill coals, well-developed underclay is absent. The coal in the mine is banded, remarkably free of partings, locally capped with bony coal, moderate in ash, and high in sulfur.

Elsewhere in Elk County, the one other abandoned underground mine in the Luthersburg coal is also elongate, though less pronounced.

It is important to note that channel coals need not be thick. However, unless encountered incidentally, it is only where such coals are thick that there is sufficient economic incentive to mine them and consequently determine their three-dimensional geometry. Thus, many channel-coal deposits may go unrecognized or undetected.

INTERPRETED DEPOSITIONAL ENVIRONMENTS. It is likely that at least the thick Luthersburg coal in Elk County originated as peat in stagnant or standing water mostly in rapidly abandoned, sinuous stream channels. Accommodation space, thickness of coal, and lack of partings or impurities in the channel-fill coals indicate that the stream channels were rapidly abandoned and subsequently relatively stable and isolated so that the accumulating peat was not subject to influxes of fine-grained sediment from across the floodplains.

Abandoned channels such as these, which fill in very slowly and have a good chance of preservation, represent a depositional setting that is potentially rich in extraordinary (rare) fossil faunal assemblages (Hook and Ferm, 1985; Dodge, 1992). Animal remains would have accumulated in the channel bottoms and been preserved in the anoxic, organic-rich mud, which later became dark shale. No attempt has ever been made to search for such fossils in the floor of the Caledonia No. 13 mine. Unfortunately, the area around the mouth of the No. 13 was surface mined and backfilled in the early 1980's, thus precluding access to critical exposures.

Water depth within the abandoned channels was shallow enough to support luxuriant plant growth. The channel vegetation was ultimately transformed into banded coal. Formation of underclay (paleosol) was inhibited by submergence of the channel bottom, lack of weathering of the substrate, and insufficient time to develop soil prior to peat accumulation.

The channel coal pinches out along the channel margins, and relatively thin, scattered patches of coal, in places underlain by well-developed underclay, may represent small, isolated peat bogs or mires that formed locally within shallow depressions on the floodplains.

The paucity of sandstone in the Luthersburg interval in Elk County suggests that the paleochannels represent low-gradient, suspended-load tributary streams that presumably flowed into trunk streams elsewhere. These ancient trunk channels are now occupied by the Upper Worthington sandstone.

The paleoclimate during Luthersburg time was probably tropical wet-dry seasonal (Cecil and others, 1985; Dodge, 1992).

CONCLUSIONS. Recognition of the depositional environments of the Luthersburg coal has both scientific and economic importance. The fluvial character of the Luthersburg interval provides insight into the size, shape, and distribution of the coal bodies, but reliable estimation of coal resources still requires considerable subsurface data. Although the Luthersburg coal was formerly mined in Elk County, the relatively small size of the coal bodies and high cost of intensive exploration probably make further exploitation uneconomical in the foreseeable future, unless perhaps incidental in surface mining.

Finally, one must never underestimate the knowledge and experience of our local residents. Through their keen insight, lucid observations, and overall interest, they are an indispensable source of information on the geology and mining history of both Elk County and the Commonwealth.

The author thanks New Shawmut Mining Company, Saint Marys; Hepburnia Coal Company, Grampian; and Hess and Fisher Engineers, Inc., Clearfield, for providing the records and maps that form the basis of this study. The late Lewis Burch, mining surveyor, provided valuable information on the internal appearance and character of the "banana" mine.

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Yo-Ho-Ho and a Bottle of Unrefined Complex Liquid Hydrocarbons

by John A. Harper
Pennsylvania Geological Survey

Have you ever tasted crude oil? Probably not! In fact, most people would react to the question with disgust. If you have ever been near an oil well, oil pipeline, tanker, or refinery, you are undoubtedly familiar with the sight and odor of this liquid hydrocarbon. Pennsylvania's crude oil, called Penn Grade crude, often looks and smells pretty bad. Although it ranges in color from pale amber to pitch black, depending on its composition, most people familiar with the substance probably associate the words *crude oil* with a disgusting dark-green color and an odor reminiscent of some of the more volatile cleaning fluids, not an especially appetizing description. To make matters worse, a list of the chemical components in crude oil would make the Environmental Protection Agency's most wanted hit-list.

Many of us are familiar with the following more common uses for crude oil from our history books: applying it as waterproofing for clothing and canoes; mixing it with flour to create an excellent-quality axle grease and cheap lubricant; and burning it for inexpensive, albeit smoky, light. It is also an excellent furniture polish.

There was a time, more than 100 years ago, however, when many people not only tasted crude oil willingly but relished it as the cure for a plethora of medical problems, both internal and external. Both the Native Americans and the early settlers found "Seneca oil" or "rock oil" an excellent curative for burns, bruises, and old sores, and especially as a liniment for various "rheumatick" complaints. Some people even found the oil-laced waters of Oil Creek in Venango County a gentle but effective laxative (Giddens, 1947). Later, one man in particular made special use of the supposed curative properties of Penn Grade crude oil.

SAMUEL KIER AND THE SALT WORKS. Samuel M. Kier (Figure 1) was born in Saltsburg, Indiana County, but moved to Pittsburgh at the age of 21. He was an industrial explorer who dabbled in numerous enterprises with mixed success. His first business was running canal boats between Pittsburgh and Philadelphia with his partner,

Figure 1. Samuel M. Kier, 1813–1874. Photograph courtesy of the Drake Well Museum.

James Buchanan, who would later become president of the United States. He was also involved in brick manufacturing, coal mining, steel making, and lumbering. In 1847, Samuel and his father Thomas bought some property in Tarentum, Allegheny County, for the purpose of becoming part of the salt business that thrived there. They had two wells drilled on the property to a depth of 400 feet (to the sandstones of the Pennsylvanian-age Pottsville Formation, according to Hughes, 1933) and built a small salt works to produce salt from brine. Unfortunately, the Tarentum salt wells also produced an annoying quantity of oil that contaminated the brine.

At that time, the salt manufacturers had little use for oil, which was regarded as a contaminant. It could be used as a fine spindle lubricant in manufacturing cotton yarn when mixed with whale oil (Miller, 1974), but more often than not it was discarded into the Pennsylvania Canal that ran along the floodplain of the Allegheny River. There, much to the dismay of canal boat operators, it greased towlines and soiled the decks and sides of the boats (Giddens, 1947). One day, some of the neighborhood boys threw a burning branch into the canal and set the oil aflame. The sight of the canal seemingly on fire made Tarentum residents realize that the oil was good for something after all—light. The oil produced a large amount of noxious fumes and smoke, but it worked well enough to replace whale oil and lard as the primary source of lamp light.

KIER'S PETROLEUM, OR "ROCK OIL." In 1848, when Samuel Kier's wife developed tuberculosis, the doctor prescribed "American Medicinal Oil," which came from a well in Kentucky (Miller, 1974). Kier recognized that the medicinal oil was basically the same material as the contaminant being discarded from the family salt wells. Always the enterprising businessman, he turned his wife's misfortune into a new business. He packaged the oil in half-pint bottles and sold them for 50 cents each. As part of his marketing strategy, he hired men to drive around the countryside in gaily-colored wagons to proclaim the worth of this new medicine and sell it to the public. In language that would have made P. T. Barnum proud, Kier advertised as follows:

> Kier's Petroleum, or Rock Oil, celebrated for its wonderful curative powers. A natural remedy! Procured from a well in Allegheny County, Pa., four hundred feet below the earth's surface. Put up and sold by Samuel M. Kier, 363 Liberty Street, Pittsburgh, Pa.
>
> The healthful balm, from nature's secret spring,
> The bloom of health and life to man will bring;
> As from her depths the magic fluid flows,
> To calm our sufferings and assuage our woes.

Another advertisement, in the form of a bank note (see front cover), unabashedly promised a cure for just about everything from rheumatism, gout, and blindness to the common cold. But though Kier's raw materials were basically free and the demand for his product was relatively high, he could not sell enough to make a profit. The expense of marketing ate up most of his proceeds, so he eventually withdrew his wagons and sold his oil only through drugstores.

THE FIRST OIL REFINERY. Samuel Kier continued to look for ways to obtain a profit from the previously disparaged crude oil. In 1849, sensing that there were other potential uses for it, he sent a sample for analysis to Professor James C. Booth. Booth was a prominent Philadelphia chemist and a former assistant of Henry D. Rogers, the first State Geologist of Pennsylvania during the First Geological Survey of the state. Booth recommended Kier's oil as a solvent for gutta-percha (Miller, 1974), a resin-based rubber used for molding and casting. He also suggested distilling the oil and gave Kier plans for constructing a small still. In 1850, Kier went into partnership with John T. Kirkpatrick, another Pittsburgh industrialist, and built the first still at his establishment on Seventh Avenue in Pittsburgh, near what is now the Civic Arena. The still was a small cast-iron kettle with a cover and distillation tube that had the capability of distilling one barrel of crude oil at a time. The fruits of Kier's first few attempts were as bad as the original crude, but he eventually learned to control the process and produced an oil that was at least useful for lighting. Kier called his new product "carbon oil" (McLaurin, 1896). Unfortunately, it still smelled pretty bad!

Kier, always trying to improve on things, increased production by substituting a five-barrel still, and experimented a great deal with various lamps. He finally invented a lamp that would burn his "carbon oil" with little or no smoke, and soon Pittsburgh was showing the world that Kier's oil lamps were the world's cleanest and brightest, and provided the best illumination. A few years later, a man named "Colonel" Edwin L. Drake showed up in Tarentum looking for ways to drill a well on Oil Creek near Titusville.

That was the beginning of the petroleum refining industry as we know it today. Had Kier been as clear-headed about this business venture as he was about the potential usefulness of crude oil, his descendants would be enormously wealthy today. But Samuel M. Kier never thought seriously about patenting his process or his lamp, so as Professor Booth later said to him (Giddens, 1947), "We missed it by letting this thing slip."

Still, not everyone could be convinced that crude oil was good only for lighting and lubrication. Giddens (1947, p. 18) quoted from an 1892 interview with Tarentum resident John W. Staley, published in the long-defunct newspaper *The Pittsburgh Dispatch:*

> The "rock oil" which [Kier] sold in bottles for medicine was simply the crude oil of to-day, though there is no question that that found in the Kier well was of the very best. I have taken many a dose of it inwardly, and, sir, if you ever get a bad cold in the chest, there is no better remedy to-day than to soak a flannel cloth with crude petroleum and lay it across your breast. Try it some night. In those days everybody up here in Tarentum used the Kier oil for medicine, and I'll bet you will find plenty of persons still living here who yet believes in the virtues of petroleum as a medicine. I am never without half a barrel of crude oil now in the house, and it is my standard remedy.

Drink up, me hearties!

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At the State Museum—Dino Lab: A Window to Paleontology

The State Museum of Pennsylvania in Harrisburg recently celebrated the one-year anniversary of **Dino Lab**, an interactive exhibit that offers visitors a behind-the-scenes look at fossil preparation. Lab technicians (preparators) expose fossil skeletons of dinosaurs and other prehistoric reptiles as visitors look on through one of two large windows. Supplemental information is provided by a short video, traditional exhibit explanations, and a free brochure. A closed-circuit television camera allows the museum-goer to view the preparator's work up close.

The centerpiece of the exhibit is a large block of Late Triassic mudstone (Petrified Forest Formation, Chinle Group of north-central New Mexico) that contains a number of partial and nearly complete skeletons of the small theropod dinosaur properly known as *Rioarribasaurus* (formerly *Coelophysis*). Dinosaurs similar to *Rioarribasaurus* roamed the Pennsylvania landscape during the Late Triassic Period (see *The Graterford Dino-*

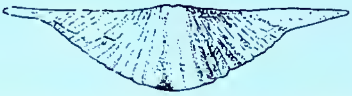
saurs—Tracking Triassic Travelers, Pennsylvania Geology, v. 25, no. 4, p. 2–9). The block was collected at Ghost Ranch, N. Mex., by personnel from the Carnegie Museum of Natural History in 1981 and was donated to The State Museum in 1993.

Since the opening of the exhibit, four additional dinosaur skulls have been discovered. The preparators, who are trained volunteers, uncover the skeletons and mechanically and painstakingly remove the matrix from the bone by using a simple pin vise and the aid of a binocular microscope.

The State Museum is continually recruiting dedicated volunteers to work in Dino Lab and/or in the Section of Paleontology and Geology. For more information about these volunteer opportunities, contact Dr. Robert M. Sullivan, Senior Curator, Section of Paleontology and Geology, The State Museum of Pennsylvania, Third and North Streets, Harrisburg, PA 17108–1026, telephone 717–783–9897.

Parking at Site 17 in *Fossil Collecting in Pennsylvania*

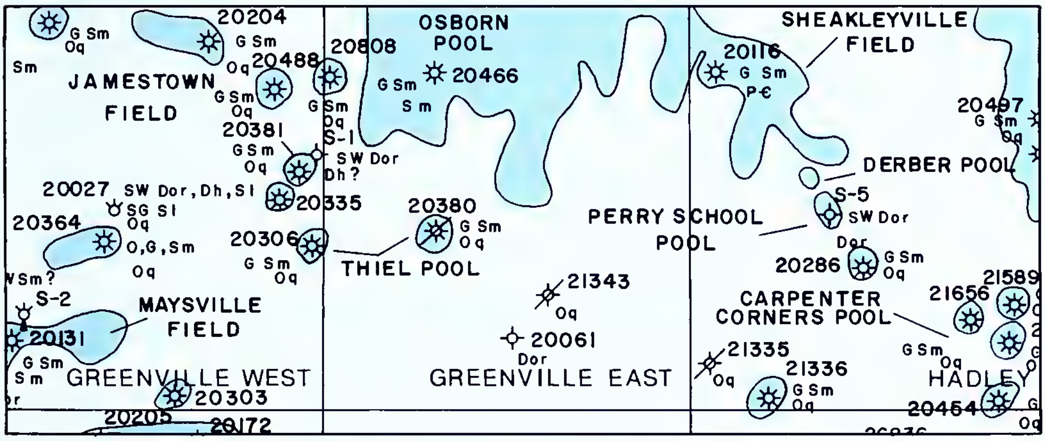
The Pennsylvania Geological Survey has received several complaints from Conrail concerning parking at Site 17—Rockville Quarry Brachiopod Locality, Dauphin County—in *Fossil Collecting in Pennsylvania* (Pennsylvania Geological Survey General Geology Report 40). Collectors are parking under the U.S. Route 22–322 bridge and thereby blocking Conrail's access road along the tracks. This has undoubtedly come about because of unfortunate wording in the directions on page 85 of the book. As written, the directions instruct collectors to "Park at the highway bridge over the railroad and walk up the hill to the quarry." Collectors should instead be instructed to park along the edge of the wide area immediately **south** of the bridge where their cars will not block the access road. Your consideration in this matter will ensure that this excellent site will continue to be available to collectors.



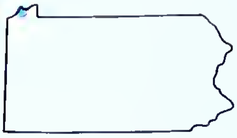
NEW RELEASES

Revised Map of Deep Wells Available

A revised and updated version of *Deep Well Oil and Gas Exploration and Development in Pennsylvania,* Open-File Report 94–01 of the Pennsylvania Geological Survey, has been completed and is now available as an ozalid (blueline or blackline) print. The report, which was last updated in 1989, consists of a map in two sheets at a scale of 1:250,000, compiled and drafted by L. J. Balogh. The map shows the locations of several thousand deep wells (wells that penetrate the top of the Middle Devonian Tully Limestone or its equivalent) in Pennsylvania. All deep wells outside established fields are shown. Only selected wells within developed areas are shown, however, because of space limitations at this scale. All wells are identified by permit number (or Survey file number for wells drilled before permitting), and information is provided regarding the formation at total depth, shows of oil, gas, and water, and producing formations. The fields and pools, many of which are named on the map, are highlighted with a stipple pattern that makes it easier to distinguish developed areas from potential exploratory areas. Open-File Report 94–01 may be ordered from the Pennsylvania Geological Survey, Subsurface Geology Section, 400 Waterfront Drive, Pittsburgh, PA 15222–4745, telephone 412–442–4235. The cost for the entire map (in two sheets) is $6.80 plus $0.48 state and local sales tax if sent to a Pennsylvania address, plus a delivery charge, which is dependent on the delivery destination.



Groundwater Quality at Presque Isle State Park



The Pennsylvania Geological Survey recently published Open-File Report 95-01, **Ground-Water Quality and Flow at Presque Isle State Park, Erie County, Pennsylvania with Emphasis on Impacts from On-Site Sewage Effluent Disposal.** The report, by staff hydrogeologist Michael Moore, includes findings from a comprehensive, three-year study of the groundwater system at Presque Isle. Initiated in 1989 at the request of the Bureau of State Parks and the Presque Isle State Park Advisory Committee, the purpose of the study was to determine whether on-site sewage treatment and effluent disposal systems in the park contributed to the elevated concentrations of fecal coliform bacteria in the nearshore lake water that result in closures of the bathing beaches.

The groundwater-flow system at Presque Isle is influenced by a complex interplay of precipitation rates, water level in Lake Erie (which is largely controlled by wind intensity and direction), vegetation activity, air temperature, soil-moisture levels, and tides. The result is a complex hydrologic system in which all precipitation leaves the peninsula as either water vapor (direct evaporation or transpiration by plants) or groundwater flow.

The principal conclusion of this investigation is that sewage effluent was not a factor in the elevated fecal coliform concentrations that closed the bathing beaches.

The most unexpected discovery was widespread, naturally occurring, high concentrations of dissolved arsenic in the groundwater. Virtually all groundwater 18 feet or more below the water table can be expected to exceed the 50 microgram per liter Maximum Contaminant Level (MCL) for arsenic in drinking water. Fortunately, park facilities have long been served by the municipal water system of the city of Erie.

The report is written for readers who have a minimum of technical expertise. Colored hydrographs are annotated to illustrate flow-system concepts. Similarly, annotated graphs are used to illustrate geochemical concepts. Appendicies include the results from the water sample analysis and statistical summaries for several data categories. Copies of the report can be obtained for $10.00, plus $0.60 state sales tax if mailed to a Pennsylvania address, from the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. Please make checks payable to *Commonwealth of Pennsylvania*.

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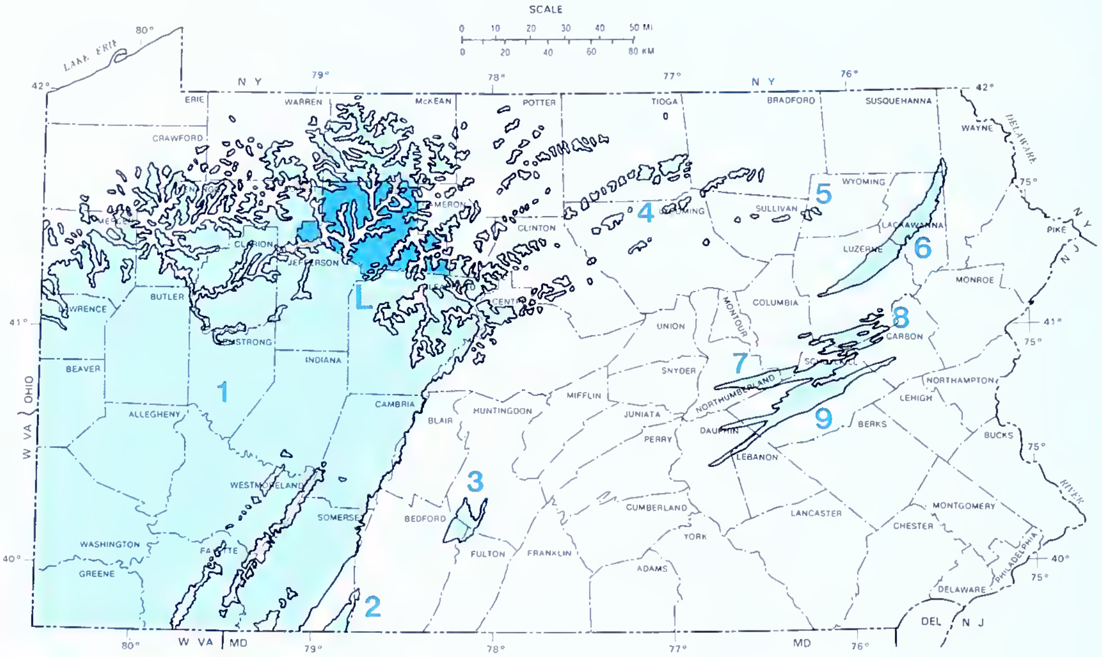
TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING

COAL FIELDS OF PENNSYLVANIA

(See article on page 2)



EXPLANATION

BITUMINOUS FIELDS
- 1 Main Bituminous
- 2 Georges Creek
- 3 Broad Top
- 4 North-Central

ANTHRACITE FIELDS
- 5 Western Northern
- 6 Northern
- 7 Western Middle
- 8 Eastern Middle
- 9 Southern

🟦 Coal measures in Elk County

L Type area of Luthersburg coal

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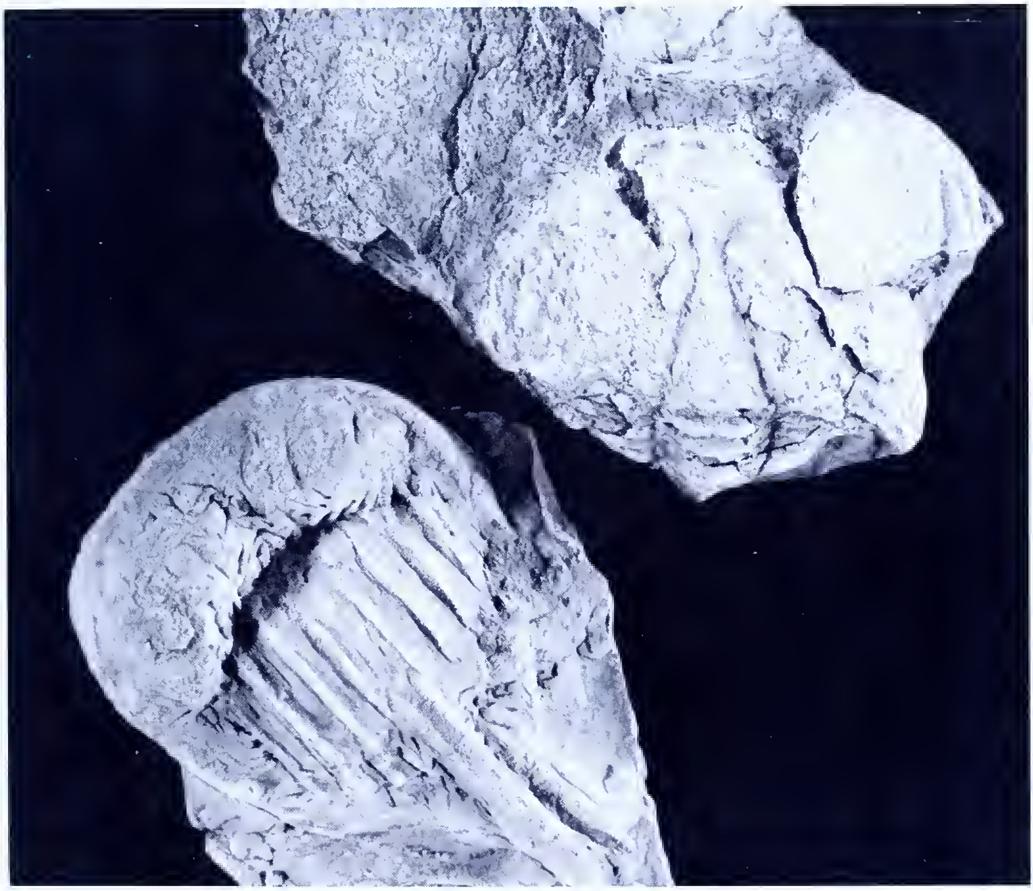

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CONTENTS

Geological products ("the times they") are "a-changin'" 1
Horseshoe crabs and their trace fossils from the Devonian of Pennsylvania 2
Biomarkers (chemical fossils) in Pennsylvania rocks 8
Announcement 14
Earth science teachers' corner 15
New release 16

ON THE COVER

Horseshoe crabs and a trace fossil produced by a horseshoe crab from the Upper Devonian Chadakoin Formation in Erie County, Pa. Body fossils of *Kasibelinurus randalli* (upper left) are part of a mass accumulation of variously disarticulated remains. The trace fossil *Protolimulus eriensis* (lower right) is a resting or burrowing trace probably produced by *K. randalli* on a tidal flat. Specimens collected by Scott C. McKenzie and deposited in the U.S. National Museum of Natural History (USNM 484524, left; USNM 484525, right); x1. Photograph by Loren E. Babcock.

PENNSYLVANIA GEOLOGY

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VOL. 26, NO. 2 **SUMMER 1995**

STATE GEOLOGIST'S EDITORIAL

GEOLOGICAL PRODUCTS ("the times they") ARE "A-CHANGIN'"

Geologic and topographic information traditionally has been provided in the form of physical products, such as printed reports illustrated with figures and tables, as well as maps that have multicolored lines and patterns to summarize complex geological data and relationships in a printed graphic format.

Printed products are very time consuming to produce. And, except for popular, educational, or selected other products, only a relatively few tens of copies of scientific reports and maps are usually required to meet user needs. Printing, however, by its very nature, is designed to produce many copies that require bulk storage.

Traditional methods of information distribution are changing. Most Survey reports reproduced for dissemination now involve some digital technology. For example, all Pennsylvania Survey reports now are prepared using word-processing computer software. Most texts of geologic and hydrogeologic reports now easily fit on one or two small computer disks. Geographic and geologic databases created from groundwater and oil and gas well records are increasingly distributed via digital methods. Compilation of base topographic maps now is almost exclusively done using digital technology.

The newly revised physiographic map of Pennsylvania (see announcement on page 16) was prepared for distribution using digital technology and can be provided to you in digital format. Graphic copies of this map can also be individually "printed" by commercial outlets, as well as by users who have access to digital printers and software that can read Arc/Info export files, rather than by standard printing, to avoid needless bulk storage. As necessary changes are made to this map, no manual drafting is required to provide an improved version.

The future of timely and economical information distribution of geological and topographic information is thus largely digital. At the Pennsylvania Geological Survey, we plan to increase digital distribution of geologic and topographic information.

In order to best serve you, the users of Survey distributed information, we seek your comments on planned information distribution

(continued on page 14)

Horseshoe Crabs and Their Trace Fossils From the Devonian of Pennsylvania

New Data Suggest Reinterpretation of Their Sedimentary Environments as Marginal Marine

by Loren E. Babcock and Marilyn D. Wegweiser, The Ohio State University; Arthur E. Wegweiser, Edinboro University of Pennsylvania; Thomas M. Stanley, Kansas Geological Survey; and Scott C. McKenzie, Erie, PA

Horseshoe crabs that thrive today along the Atlantic coast of the United States belong to an ancient group of pincer-bearing arthropods (jointed-leg animals). These fascinating creatures left numerous fossils in the Upper Devonian rocks of northern Pennsylvania and adjacent areas of New York and Ohio. Based on trace fossils and new sedimentologic evidence, the depositional environments where many of these creatures lived are reinterpreted here as marginal marine.

EVOLUTIONARY HISTORY OF HORSESHOE CRABS. The horseshoe crabs (order Xiphosurida) are a small group of arthropods whose origins date back at least 500 million years. This group commonly has been cited for its conservatism in shape and behavior. This interpretation, although not entirely correct (Fisher, 1984), may have been an inevitable consequence of the rather primitive, trilobite-like appearance of living horseshoe crabs. Also, as demonstrated by fossil examples (Figure 1), some of these creatures looked basically the same 365 million years ago as their relatives do today.

Horseshoe crabs from Pennsylvania and adjacent states belong to two extinct lineages of the order Xiphosurida (Fisher, 1984). *Kasibelinurus randalli* (Figure 1A–C and cover photograph) belongs to the ancestral group that gave rise to *"Euproops" morani* (Figure 1D) and the modern horseshoe crabs (Fisher, 1984). The familiar modern species *Limulus polyphemus* (Figure 1E) is the one that occurs in abundance along the Atlantic coast, and often it can be observed swimming in shallow nearshore waters or in estuaries, or crawling along beaches or tidal flats. The best time to see living horseshoe crabs is during the late spring and early summer, when *L. polyphemus* comes ashore in great numbers to lay eggs on tidal flats and beaches.

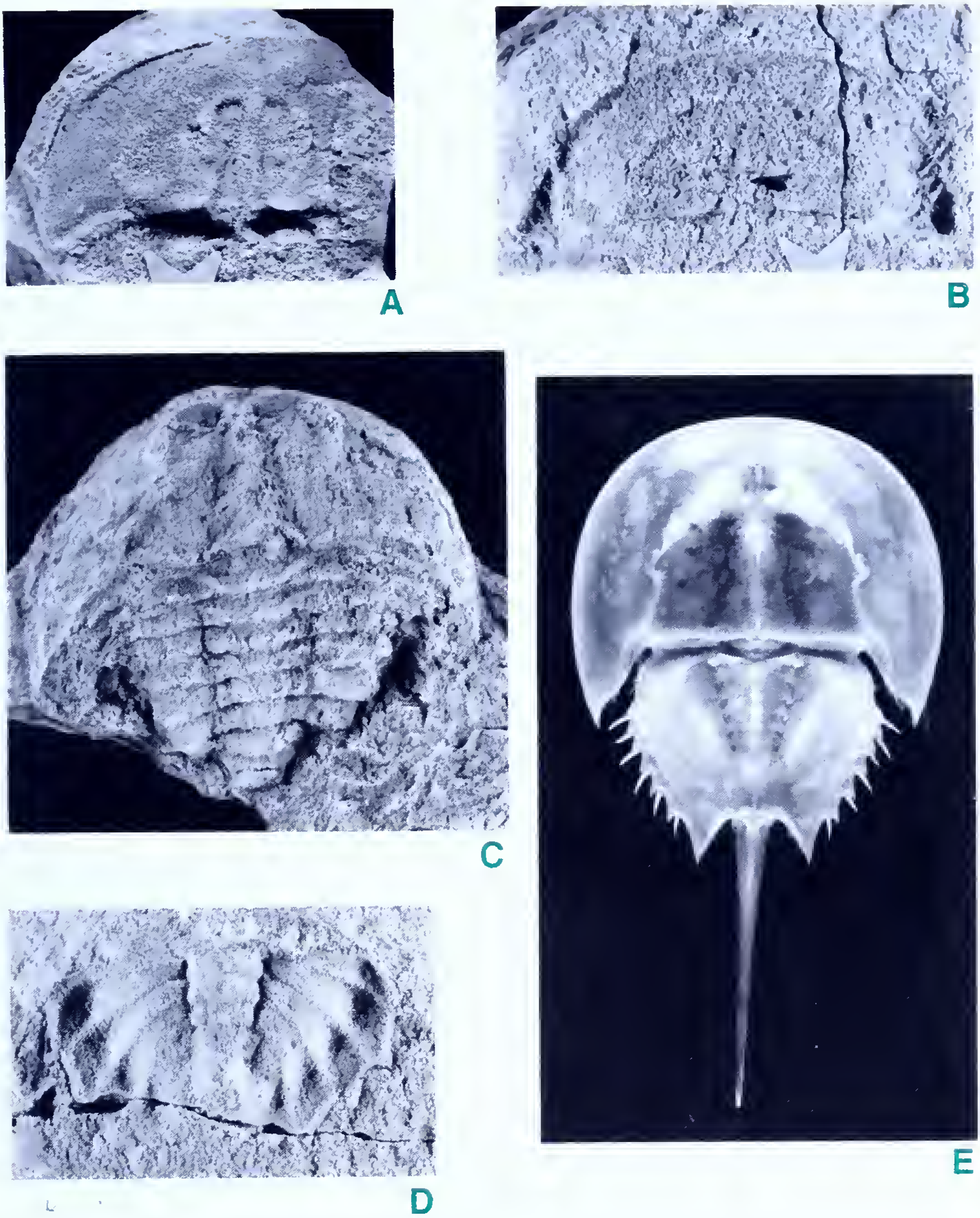


Figure 1. A. *Kasibelinurus randalli*, holotype prosoma (head shield) probably from the Venango Formation (Upper Devonian) of Warren County, Pa. (YPM 9010; x1.25). B. *Kasibelinurus randalli*, paratype prosoma from the same location as the holotype (YPM 30656; x1). C. *Kasibelinurus randalli*, a more complete specimen from the Chadakoin Formation of Allegany County, N. Y. (CM 11065; x1.25). D. "*Euproops*" *morani*, holotype abdomen from the Venango Formation of Warren County, Pa. (CM 11574; x1.25). E. *Limulus polyphemus*, Holocene (recent) from the Atlantic coast of the United States, shown for comparison (x1). Fossil specimens are in the Peabody Museum of Natural History, Yale University (YPM), and the Carnegie Museum of Natural History (CM).

TRACE FOSSILS OF HORSESHOE CRABS. Fossils of the body parts of horseshoe crabs are generally rare in Upper Devonian rocks of Pennsylvania. Evidence of their existence in the form of trace fossils produced by their movement (Figures 2, 3, and cover photograph), however, tends to be quite common in those same rocks, particularly at exposures in Erie, Warren, McKean, and Susquehanna Counties.

Trace fossils produced by horseshoe crabs include both elongate trails or trackways and resting or burrowing pits. Trails or trackways (Figure 2) are similar in shape to the better-known trace called *Cruziana*. *Cruziana* is thought to have been formed by trilobites ploughing through sediment. Other trace fossils are resting or burrowing traces named *Protolimulus eriensis* (Figure 3 and cover photograph). Previously, *Protolimulus* was regarded as being a body fossil of a horseshoe crab (Packard, 1886; Lesley, 1889). It is clear from its preservation, however, that it is actually a trace fossil. All known specimens of *Protolimulus* are impressions produced by the bottom, or ventral, side of the animal, and many specimens show distinct scratches or depressions made in sediment by the appendages or telson (tail spine).

Traces made by horseshoe crabs are commonly preserved in relief and found protruding from the undersides of siltstone or sandstone beds as natural casts. The traces were originally left in soft, unconsolidated sediment (such as silt or clay) and then filled by the rapid deposition of a silt or sand layer. After turning to rock, the less resistant shaly layers were removed by weathering and erosion, revealing detailed casts in siltstone or sandstone.

The traces are important not just because they reveal information about how early horseshoe crabs lived, but also where they lived. Because the traces were formed in unconsolidated sediments, they would have been easily destroyed by current action, and therefore

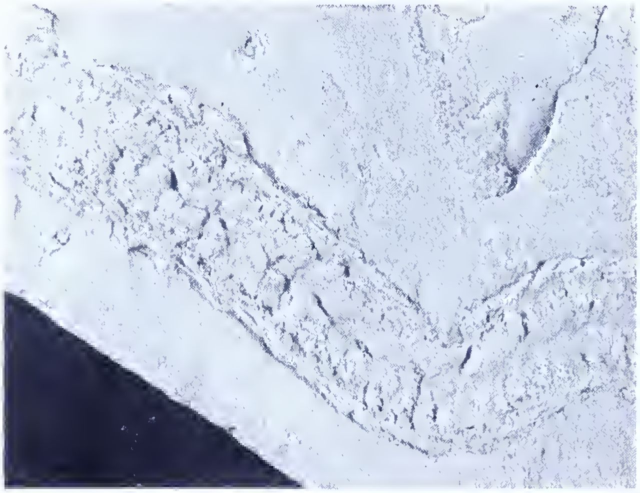
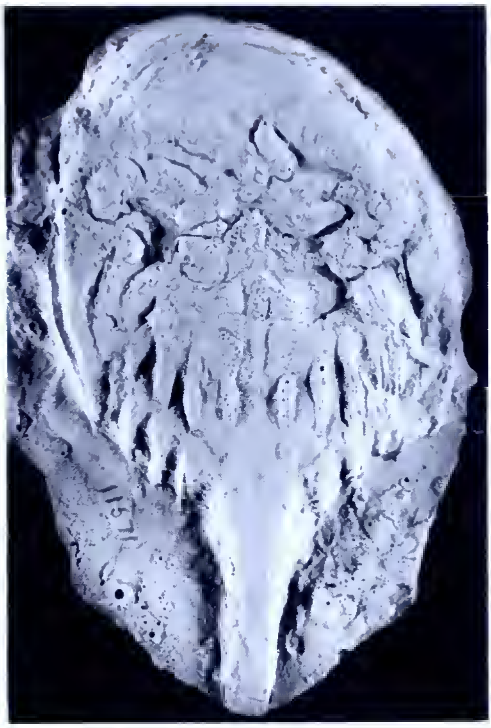


Figure 2. A trace fossil (ploughing trail) probably produced by *Kasibelinurus randalli*, from the Chadakoin Formation (Upper Devonian) of Erie County, Pa. (x0.75). The animal was moving from right to left. The specimen is in the U.S. National Museum of Natural History (USNM 484523).

Figure 3. *Protolimulus eriensis*, plaster cast of the holotype, a resting or burrowing trace probably produced by *Kasibelinurus randalli*, from either the upper Chadakoin Formation or the lower Venango Formation (Upper Devonian) of Erie County, Pa. (x0.75). The cast is in the Carnegie Museum of Natural History (CM 11571).



could not have been transported any distance. Body fossils, on the other hand, could have been transported, although most in the rock record are probably of relatively local origin. Horseshoe crab exoskeletons are remarkably resistant to disarticulation and breakdown, and can be transported tens of kilometers without showing any obvious effects of transport (Babcock, 1994). For this reason, the presence of horseshoe crab body fossils alone is insufficient evidence that horseshoe crabs were living in any one particular area. Traces of their activities that were made in unconsolidated sediment, though, show that horseshoe crabs lived in the places where the traces have been preserved.

STRATIGRAPHIC SETTING AND DEPOSITIONAL ENVIRONMENTS. Horseshoe crab body or trace fossils are present in the Chadakoin, Venango, and Catskill Formations of Pennsylvania. In adjacent states, they are found in equivalent strata representing marginal marine to nonmarine depositional environments. The type specimens of *Kasibelinurus randalli* (Figure 1A and 1B) are apparently from the oil sands of the Venango Formation in Warren County, Pa. Since the time that Beecher (1902) named *K. randalli,* additional horseshoe crabs have been found in the Chadakoin and Venango Formations. Among them is a single specimen of "*Euproops*" *morani* (an incomplete abdomen, Figure 1D) from the Venango Formation of Warren County. The Chadakoin and Venango Formations are currently regarded (Berg and others, 1986) as being of late Famennian (late Devonian) age.

Trace fossils produced by horseshoe crabs are among the more common fossils in the upper Chadakoin and lower Venango Formations of Erie, Warren, and McKean Counties, Pa. Two places where they may be collected have been described by Hoskins and others

(1983) as localities 19 (Erie County) and 53 (Warren County). Additional specimens have been reported from the Catskill Formation of Susquehanna County (Caster, 1938).

Kasibelinurus randalli and "*Euproops*" *morani* probably lived in a marginal marine to nonmarine environment. For parts of the Chadakoin and Venango Formations at least, this interpretation differs markedly from previous views concerning the depositional environments of these units. Previous interpretations (for example, White, 1881; Caster, 1938) were principally based on the types of body fossils present in the units. The body fossils include brachiopods, molluscs, sponges, fish parts, crinoid pieces, horseshoe crabs, and abundant terrestrial plant remains. Most of the animal fossils seem to be of shallow-marine origin. It is possible that some of the animals could tolerate nearshore brackish water, although sedimentologic evidence suggests that most of the fossils were washed into marginal-marine to nonmarine environments by waves.

Sedimentologic characteristics of the rocks provide the strongest evidence of the depositional environments of the upper Chadakoin and lower Venango Formations in northwestern Pennsylvania. This succession mostly consists of siltstones, sandstones, and conglomeratic sandstones. Red beds, which are generally indicative of nonmarine sedimentation, are common. Siderite (iron carbonate), which often forms in marginal-marine areas that are influenced by freshwater influx from streams, is a common mineral in these units. Sedimentary structures include symmetrical to slightly asymmetrical ripple marks, flaser bedding, reactivation surfaces, intraclastic conglomerates, and mud cracks. Symmetrical ripple marks normally form in shallow, relatively quiet water by the oscillation of currents, whereas asymmetrical ones form where a unidirectional current is present. Flaser bedding develops mostly in tidal and stream environments where thin streaks of mud have accumulated in troughs of sand ripples. Reactivation surfaces are places where sedimentation of a single, migrating bed of unconsolidated sediment has stopped and another migrating bed has been deposited on top. They are formed where changes in flow rates, tidal stage, or tidal current direction occur. Intraclastic conglomerates are formed by the rip up and nearby redeposition of mud chips. Commonly, the mud chips are pieces of semihardened sediment that have broken from mud cracks on sun-dried mudflats. Mud cracks, which result from the wetting and drying of sediment, show unequivocally that some of the upper Chadakoin and Venango strata were subaerially exposed at times.

Finally, the abundance of horseshoe crab trace fossils offers evidence that the upper Chadakoin and lower Venango Formations were deposited in marginal-marine to nonmarine environments. Many similar trackways in the rock record are from estuarine (brackish water) and tidal-flat settings (Miller, 1982; Pickett, 1984), including those from the Catskill Formation of Pennsylvania (Caster, 1938). These are the environments where many potentially preservable horseshoe crab tracks are being formed during modern times. The sediment must be cohesive (wet) enough at the time the animal passes through it for a trace to be preserved, and the environment must inhibit the existence of other creatures that subsequently could burrow through the sediment and destroy the trace. Such conditions occur commonly in marginal-marine, brackish-water, and freshwater settings.

The authors thank R. D. White, Peabody Museum of Natural History, Yale University, and J. L. Carter and A. Kollar, Carnegie Museum of Natural History, for arranging loans of specimens described in this article. L. I. Anderson, University of Manchester, provided taxonomic advice. G. J. Wasserman, The Ohio State University, printed the photographs. This work was supported in part by a grant from the National Science Foundation to L. E. Babcock and a grant from the Pennsylvania Bureau of Topographic and Geologic Survey to M. D. Wegweiser.

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Biomarkers (Chemical Fossils) in Pennsylvania Rocks

by Christopher D. Laughrey
Pennsylvania Geological Survey

Many readers of *Pennsylvania Geology* are familiar with articles that contain descriptions of the abundant and diverse fossils found in Pennsylvania's rocks. Fossils provide a natural record of ancient plant or animal life. Rarely, the original material of an ancient organism is preserved unaltered, such as the frozen remains of woolly mammoths found in Siberia. A good local example of preservation of unaltered material is the recent discovery of the carbonate mineral aragonite in the shells of numerous molluscs in the Pennsylvanian-age Brush Creek marine zone of the Conemaugh Group in western Pennsylvania (Cercone and others, 1989). A newly recognized example of preservation of unaltered to slightly altered biologic material is described in this article.

INTRODUCTION TO CHEMICAL FOSSILS. Certain organic chemical compounds qualify as fossils. The presence of organic chemical compounds in rocks has long been known, but scientists previously thought that these materials had no paleontological or biological value because of extensive degradation during deposition. We now know that this presumption is quite wrong and that many organic molecules can persist virtually intact, or at least in recognizable form, for many millions of years. Mackenzie (1984, p. 115) defined these chemical compounds, called *biomarkers,* as "any organic compound detected in the geosphere whose basic skeleton suggests an unambiguous link with a known, contemporary natural product." The term "skeleton" in this definition refers to the chemical structure of the molecule.

Geochemists use stick figures, such as those shown in Figure 1, to illustrate the skeleton of an organic compound. For example, the stick figure in Figure 1A is of a chlorophyll molecule, which consists of two principal parts, porphyrin and phytol. The porphyrin part is a complex organic compound made up of several interconnected ring structures, each of which contains four carbon atoms and one nitrogen atom. The phytol part is an alcohol whose role is to aid the porphyrin in chemically associating with specific proteins within the cell membranes of organisms.

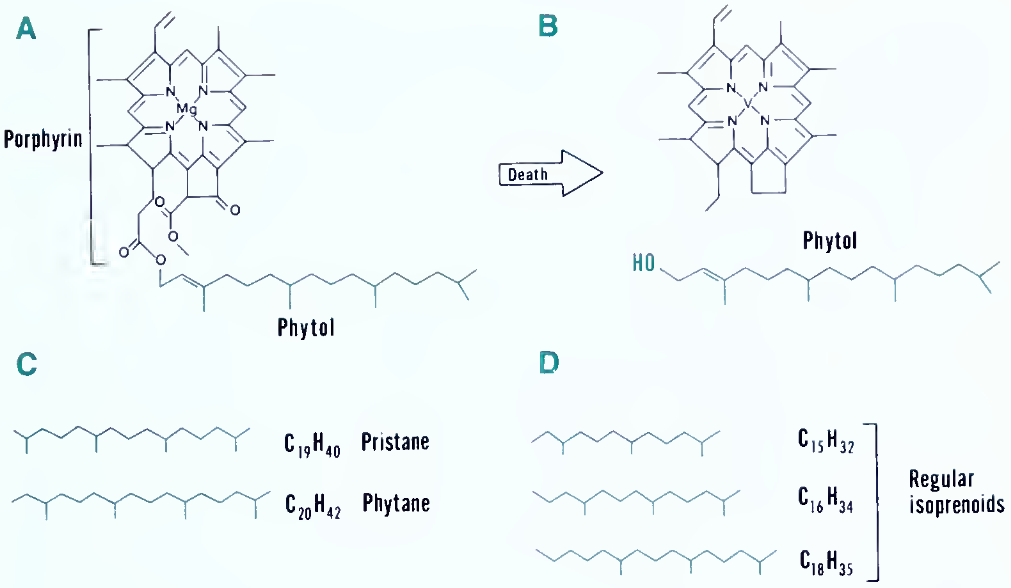

Figure 1. Biomarkers from the chlorophyll molecule. A. Chlorophyll consists of two principal parts, a porphyrin structure and a phytol structure. B. When the chlorophyll-bearing organism dies, these two parts separate. The magnesium (Mg) in the porphyrin is replaced by a vanadyl ion (V) and this new structure becomes a common biomarker found in many crude oils. C. In the presence of oxygen (high Eh), the phytol is converted to pristane. In the absence of oxygen (low Eh), the phytol is converted to phytane. D. These molecules can then be degraded further to form other molecules, called regular isoprenoids.

Let us follow the fate of the phytol skeleton in a molecule of the plant pigment chlorophyll as it decomposes in a sedimentary environment. As chlorophyll decays in sediment on a sea or lake floor, it breaks down into parts of the original molecule (Figure 1B). The now separate porphyrin and phytol parts are further modified in the depositional environment. The fate of the phytol molecule depends to a large extent on the chemistry of the water. If the water column and bottom sediment contain adequate dissolved oxygen, the phytol molecule is oxidized to an organic acid which eventually degrades to a hydrocarbon called pristane (Figure 1C). If reducing conditions prevail, the phytol is readily hydrogenated and reduced to a hydrocarbon called phytane (Figure 1C). In both cases, fragmentation of these diagenetic products may yield other biomarker compounds (Figure 1D). All of these biomarker molecules bear the vestige of their parent phytol derived from the chlorophyll material.

Biological markers have a great variety of chemical structures, all distinctly indicative of a biological origin. Hydrocarbons that form straight-chain molecular structures called *n-alkanes* (the *n* means normal) are common constituents in the leaf waxes of higher plants and in the membrane lipids of algae and bacteria. The skeletal chain lengths of these compounds provide information as to the origin of organic matter in a sediment or rock. Short-chain compounds having 15 to 19 carbon atoms and medium-chain compounds having 20 to 24 carbon atoms generally are the product of algal and/or bacterial sources (Figure 2). Longer chain compounds, with 27 to 33 carbon atoms, characterize a higher type of plant.

Many different biomarkers can provide information concerning the general environmental setting of a rock at the time of deposition. For example, a group of compounds of bacterial origin called hopanoids, which are ubiquitous constituents of many sedimentary rocks, often reflect reducing to anoxic conditions in the sedimentary environment (Peters and Moldowan, 1993). Hopanoids belong to a diverse assemblage of biomarkers known as *terpanes*. Terpanes are cyclic hydrocarbon compounds largely derived from bacterial membrane lipids (Peters and Moldowan, 1993). *Steranes* comprise another assemblage of biomarkers which are derived from compounds called sterols (which include, for example, the infamous cholesterol) that are formed by living organisms (Hunt, 1979). The relative concentrations of certain steranes and terpanes provide information on the depositional input of algae and higher plants versus bacteria in the original depositional environment (Peters and Moldowan, 1993).

A BIOMARKER EXAMPLE FROM NORTHWESTERN PENNSYLVANIA. Several biomarkers have been recovered from rock core of the Upper Devonian Huron Shale obtained during the drilling of a gas well on Presque Isle in Erie County. Using the biomarkers, we can determine the environmental conditions in an epeiric sea about 360 million years ago.

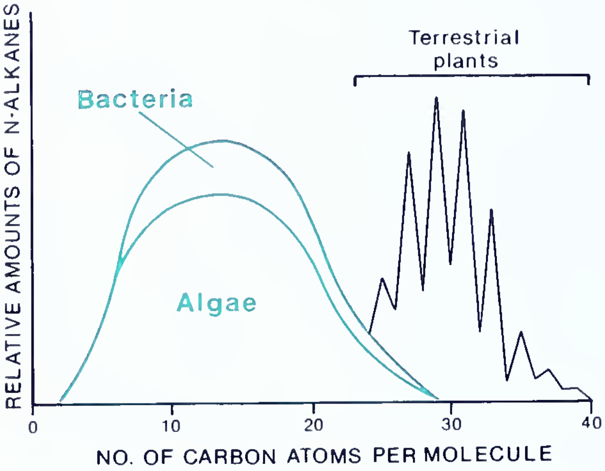

Figure 2. Selected chain-length distributions (number of carbon atoms) for n-alkanes from different kinds of organic matter in sedimentary rocks.

Table 1 is a list of the principal biomarkers identified from the Huron Shale core, their presumed biological origin, and the interpreted depositional environment in which they originated. The n-alkanes in the Huron Shale are of medium molecular weight having 10 to 36 carbon atoms (nC_{10} to nC_{36}). The nC_{11} (short for the hydrocarbon $C_{11}H_{24}$) molecule dominates the n-alkanes in the rock, whereas compounds above nC_{20} are negligible (Figure 3). This n-alkane distribution is typical of hydrocarbons generated during the degradation of marine algae (Martin and others, 1963; Tissot and Welte, 1984).

All five of the regular *isoprenoids* (Figure 1C and 1D) occur in the Huron Shale (Figure 3). Pristane and $i\text{-}C_{16}$ (an isoprenoid molecule with the tongue-tying name 2,6,10-trimethyltridecane) are the most abundant of this class of biomarkers. All of these compounds probably originated in the phytol side chain of chlorophyll associated with marine algae in the Late Devonian Catskill sea. The predominance of pristane over phytane suggests that the seawater contained free oxygen and that the topmost layers of sediment were at least moderately aerated during part of the deposition of the shale. Lesser amounts of phytane in the samples indicate that the depositional environment of the shale was at least partially suboxic or dysoxic at times; that is, periodic oxygen depletion occurred in the Huron Shale depositional regime.

The distribution of hopanoids, derived from bacterial membranes, supports the above interpretation. Geochemists use the relative distri-

Table 1. ***Biological Origin and Depositional Environments of Biomarkers from the Huron Shale***

BIOMARKER	BIOLOGICAL ORIGIN	DEPOSITIONAL ENVIRONMENT
n-alkane	Phytoplankton; benthic algae	Shallow marine
Regular isoprenoids	Phytol side chain in phototrophic organisms; archaebacteria	Oxic to suboxic shallow marine
Other terpanes		
Tricyclic	*Tasmanities*[1]	Shallow marine
Tetracyclic	?	High salinity
Norneohopane	Bacteria	Clay-rich sediment, oxic to suboxic conditions
Steranes		
C_{27} to C_{29}	Algae and higher plants	Shallow marine
Norcholestane	Bacterial oxidation of larger steroids	Nonspecific
Diasterane	Sterols	Oxic, clay-rich sediments

[1] Algal microfossil.

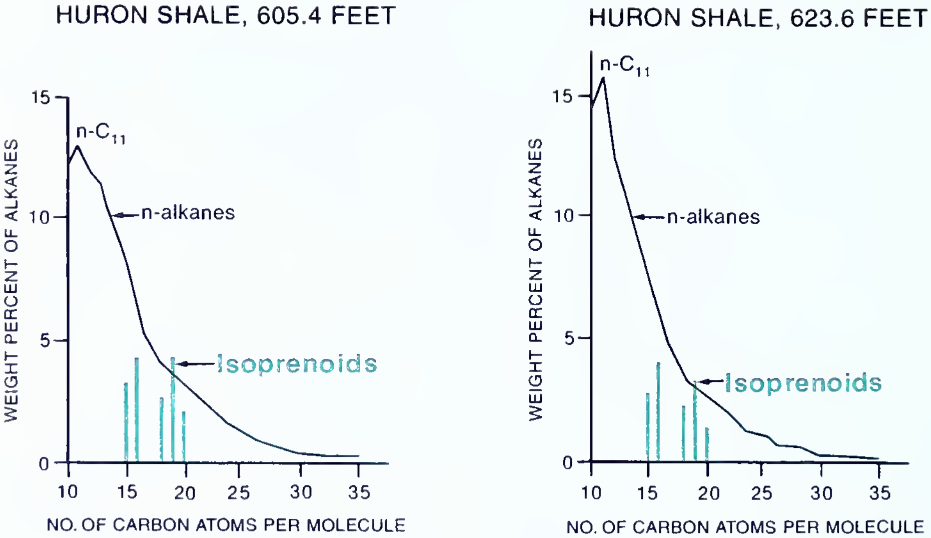

Figure 3. Distributions of n-alkanes and regular isoprenoids in two core samples of the Huron Shale. The vertical axes of the graphs represent the weight percent of alkane hydrocarbons in the samples. The normal alkanes (n-alkanes) have straight-chain structures. Isoprenoids have branched-chain structures, as shown in Figure 1D. The horizontal axes show the number of carbon molecules in the alkanes. Alkanes from $C_{10}H_{22}$ to $C_{36}H_{74}$ occur in the shale, but those from nC_{10} to nC_{20} predominate. All five regular isoprenoids (Figure 1C and 1D) occur in the samples.

bution of certain hopanoids as an indicator of the reducing-oxidizing (redox) potential (Eh) during and immediately after deposition of an organic-rich sediment. For example, large concentrations of C_{33}, C_{34}, and C_{35} hopanoids compared to C_{31} and C_{32} hopanoids indicate highly reducing (low Eh) marine conditions with no available free oxygen during deposition (Peters and Moldowan, 1993). When free oxygen is available in the depositional environment, however, the precursor materials are converted to C_{31} and/or C_{32} hopanoid biomarkers, which reflect the oxic to suboxic depositional conditions (Peters and Moldowan, 1993). Figure 4 shows the relative distribution of these hopanoid biomarkers in the Huron Shale. C_{31} and C_{32} clearly dominate the distribution of these compounds in the shale, indicating oxic to suboxic sedimentary conditions. The presence and relative amounts of other biomarkers such as norneohopane and diasterane (Table 1) also indicate oxic to suboxic conditions in the Huron Shale.

The biomarker data from the Huron Shale core contradict the most popular theories concerning the processes that concentrated large amounts of organic matter in the Devonian black shales of the Appalachian basin. Many geologists believe that the Devonian shales

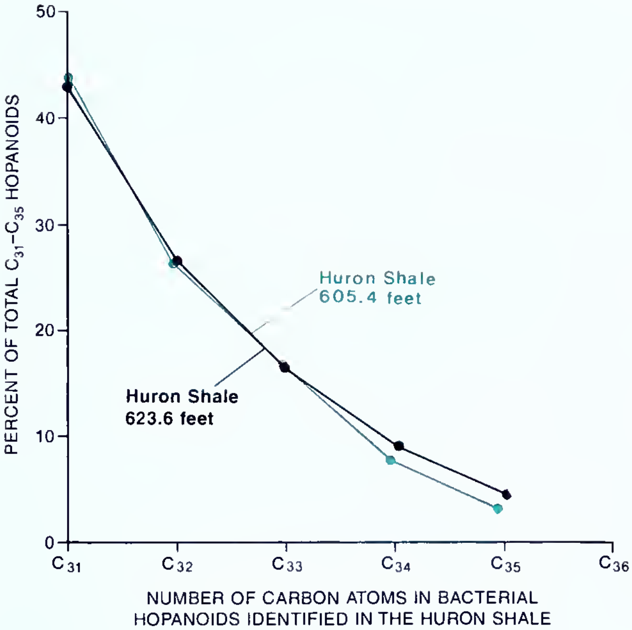

Figure 4. Relative distribution of hopanoid biomarkers in two samples of the Huron Shale. The vertical axis represents the percentage of hopanoids that have 31 to 35 carbon atoms in their structure. The horizontal axis represents specific hopanoid compounds.

were deposited in anoxic environments at great depths. A small minority of scientists, however, argue that the high organic content of the Devonian black shales is the result of high productivity of organic matter in an oxic shallow marine environment in combination with a moderate to high sedimentation rate (Tyson and Pearson, 1991; Milici, 1993). The biomarker data presented here support the latter theory and suggest that further research along these lines is warranted.

Biomarkers are fascinating fossils, and paleontology at the molecular level is as exciting as collecting sea shells from an outcrop. Biomarkers can significantly enhance a great variety of geological and biological work. The biomarkers identified in the Huron Shale testify that marine plankton and benthic microbial organisms were important life forms in the Late Devonian shallow seas of northwestern Pennsylvania. They also indicate that there is still much to learn about the sedimentary origins of some of the most studied rocks in the world.

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ANNOUNCEMENT

Free Topographic Maps

As a result of the ongoing program to revise and update 7.5-minute topographic quadrangle maps of Pennsylvania, the Survey has a stock of surplus 7.5-minute topographic maps that have been superceded by newer editions. These surplus maps are being offered at no charge, singly or in small quantities, to interested parties. Because there are too many maps to list here and because selection of individual quadrangles is not possible, we ask that those interested in obtaining the maps specify how many quadrangles, and the number of copies of each, are desired from northeast, north-central, south-central, southeast, northwest, or southwest Pennsylvania. As long as supplies last, we will mail maps from the region(s) indicated. To obtain maps, or for more information, please contact Richard Keen, Librarian, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg PA 17105–8453, telephone 717–783–8077.

State Geologist's Editorial *(continued from page 1)*

services. Are you ready to receive digital data that will allow you to reproduce your own maps, or duplicate the texts and illustrations of reports and maps that we prepare, but do not publish via traditional printed methods?

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Sandcastle Moats and Petunia Bed Holes... A New Book About Groundwater

by Dawna Yannacci
Pennsylvania Geological Survey

A colorful and interesting introduction to the basics of groundwater is now available free of charge from the Department of Environmental Protection. This 28-page booklet is entitled **Sandcastle Moats and Petunia Bed Holes...A Book About Ground Water.**

The booklet is geared toward junior high school students; however, it could also be used by teachers at all levels as a source of ideas on how to explain and demonstrate basic groundwater concepts. It is filled with colorful illustrations and helpful analogies designed to aid in the understanding of this potentially confusing subject.

Simple experiments, which demonstrate a water table, porosity, permeability, groundwater acidity, leaching, and landfills, are also described. Follow-up questions based on these experiments are provided.

Adults may find the tone of this booklet somewhat condescending, but those who keep in mind that it was written for school children will find a fun and understandable introduction to groundwater principles.

The booklet was originally written by Pat Nickinson for the Virginia Environmental Resources Center and has been adapted by James Ulanoski, Nancy Spangenberg, and Stuart Reese of the Bureau of Water Quality Management for use in Pennsylvania. This adaptation includes a special section in which the groundwater characteristics of the seven regions (physiographic provinces) of Pennsylvania are briefly discussed. In this section, the reader is given an overview of the major rock types and corresponding aquifer types, potential and known water-quality problems, and yielding capability of each region.

Sandcastle Moats and Petunia Bed Holes...A Book About Ground Water may be obtained by writing the Department of Environmental Protection, Bureau of Water Quality Management, P. O. Box 8465, Harrisburg, PA 17105–8465, or calling Marilyn Keifer at 717–787–9633.

NEW RELEASE

Digital Physiographic Provinces Map of Pennsylvania

The Pennsylvania Geological Survey announces the release of a digital data set entitled **Physiographic Provinces of Pennsylvania.** The data set is based on the recently completed third edition of the Survey's physiographic provinces map, by staff geologist W. D. Sevon.

The new map has several differences from the previous version, mainly in the Appalachian Plateaus province, where two sections, the Allegheny Plateau Section and the Deep Valleys Section, have been added and the boundaries of several other sections have been modified (see back cover).

The digital work was done by staff of the Survey's Geologic and Geographic Information Services Division using Arc/Info (Unix version) software. The boundaries of provinces and sections were digitized from 1:100,000-scale stable-base mylars, and each polygon was attributed with the name of the province and section. Separate coverages were prepared for the late Wisconsinan glacial border, which forms the boundary between physiographic sections in several areas, and the state and county boundaries and names, which were derived from the U.S. Geological Survey 1:100,000-scale digital-line-graph files.

The data set is available as Arc/Info export files for each coverage (physiographic boundaries and names, file size approximately 980 Kb; state and county boundaries and names, approximately 490 Kb; and late Wisconsinan glacial border, approximately 360 Kb). The data set also includes a plot file for printing a 1:500,000-scale, full-color version of the map using Arc/Info software and a raster plotter. An expanded map explanation shows the dominant topographic form, local relief, underlying rock type, geologic structure, approximate minimum and maximum elevations, drainage patterns, boundaries, and origin of each section.

Those interested in obtaining a copy of the data set will be asked to supply a Colorado 250-type blank tape for DOS-based PC's, or a blank 8-mm tape for Unix workstations. For more information or to order, please contact Christine Miles or Thomas Whitfield, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, telephone 717–787–8162.

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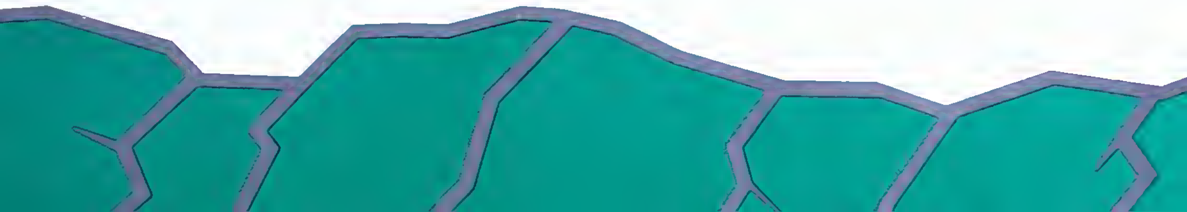
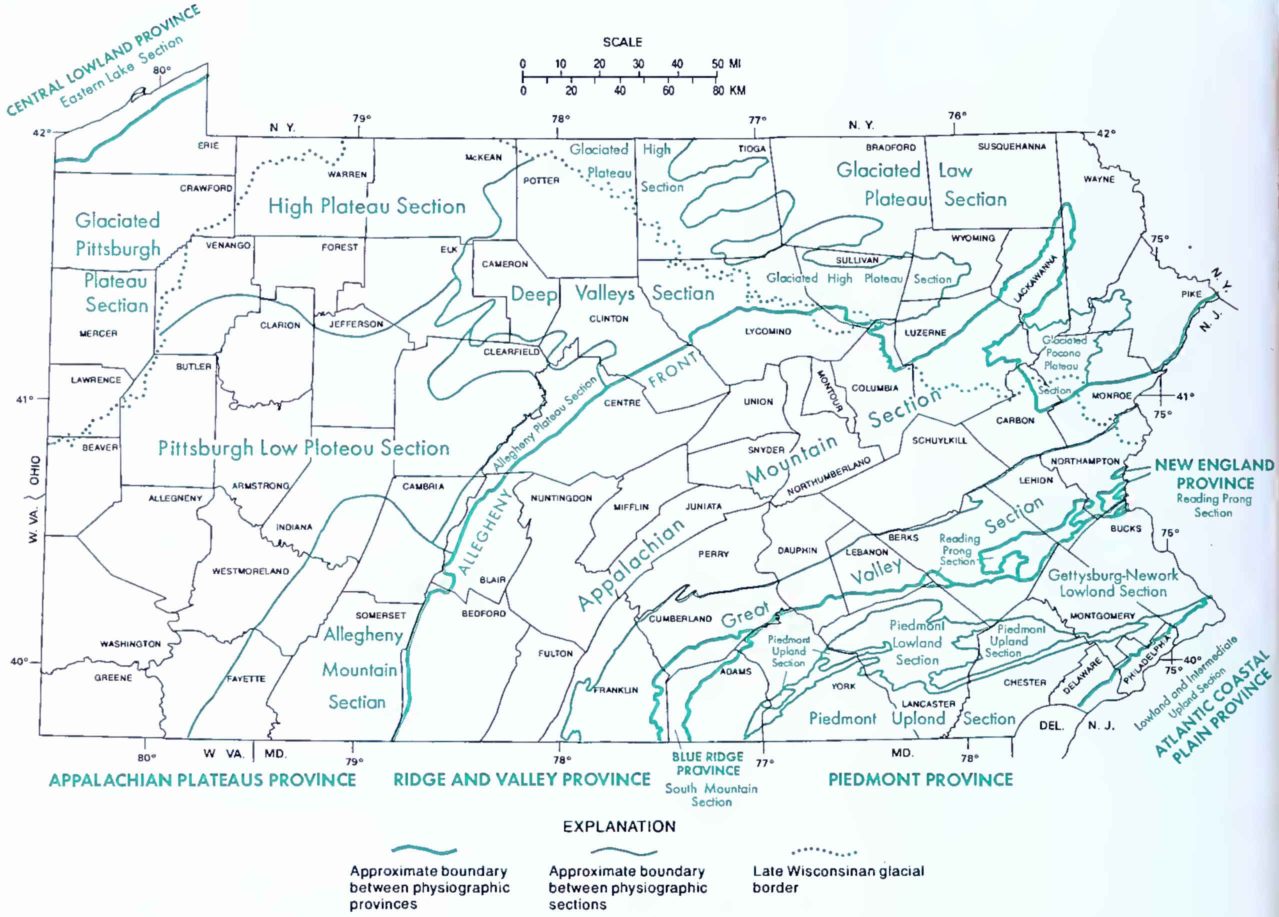


NEW PHYSIOGRAPHIC PROVINCES MAP OF PENNSYLVANIA

(See articles on pages 1 and 16)



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CONTENTS

Pennsylvania's Geological Survey becomes part of new Department of Conservation and Natural Resources 1
An explosive case of man-induced stream potholes 2
New releases 8
  Warren County bedrock geologic map and structure-contour map 8
  Freeburg quadrangle bedrock geologic map 9
  Sinkholes and karst-related features of York and Adams Counties 9
  Edinboro North quadrangle bedrock geologic map 10
  Military geology of Richmond and Petersburg National Battlefield Parks 11
  Surficial materials in parts of York, Lancaster, and Chester Counties 11
  New geologic maps 12
  Coal resources of Indiana County 14
  How to order open-file reports 15
Announcement—Internet distribution list 15
New digital products—Digital orthophoto quarter-quadrangles and digital raster graphics 16

ON THE COVER

Shot hole in the bed of Pine Creek, Allegheny County, in the process of becoming a pothole (see article on page 2). This is the same hole as that shown in Figure 3 on page 6, but was photographed 5 years later. Most of the specific features of the weir are still recognizable, but the central bore hole and many of the radiating fractures have been deepened and widened. The scale is 1 meter in length. Photograph by J. A. Harper.

PENNSYLVANIA GEOLOGY

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Pennsylvania's Geological Survey Becomes Part of New
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

With the passage of Act 18, the Department of Conservation and Natural Resources (DCNR) came into being on July 1, 1995. DCNR was created to provide a cabinet-level status for the Commonwealth's natural (including geological) resources.

The Bureau of Topographic and Geologic Survey, one of the oldest state bureaus, was transferred by Act 18 to the new DCNR as one of five program bureaus. These include the Bureaus of State Parks, Forestry, Recreation and Conservation, and Facility Design and Construction.

The mission of DCNR is to maintain and preserve state parks; manage state forest lands to assure their long-term health, sustainability, and economic use; provide information on Pennsylvania's ecological and geological resources; and administer grant and technical assistance programs that will benefit rivers conservation, trails and greenways, local recreation, regional heritage conservation, and environmental education programs across Pennsylvania.

The Bureau of Topographic and Geologic Survey, familiarly called the Pennsylvania Geological Survey, will continue to focus on providing basic geological and topographic data and assistance to all who need information about, and explanations of, Pennsylvania's complex geology and varied topography. During the first year, we will also focus our Bureau resources on supporting DCNR initiatives to educate the public about our program and accomplishments. We also will assist our colleague program Bureaus in promoting community conservation partnerships and encouraging tourism and economic development opportunities.

At the same time, we will continue to provide new geologic and topographic maps, reports, and data, particularly in digital format, that result from basic data collection of groundwater, energy, and mineral resources, and from areal mapping. As an example, we are cooperating with the National Mapping Division of the U.S. Geological Survey in providing new topographic-map digital data for Pennsylvania. One of the principal products now being produced through this federal-state partnership is digital images (called digital raster graphics; see

(continued on page 15)

An Explosive Case of Man-Induced Stream Potholes

by John A. Harper
Pennsylvania Geological Survey

POTHOLES, POTHOLES, AND MORE POTHOLES. As the citizens of Pennsylvania are well aware, potholes are an endemic feature of the Commonwealth. The annual freeze-thaw cycle of late winter and early spring, combined with the routine hammering of tires on some of the nation's most heavily traveled roads, contributes to more than a few flat tires, front-end misalignments, and damaged suspension systems every year. But Pennsylvania's roads are not the only locations of potholes. Some streambeds have developed potholes where the bed is formed of resistant, relatively homogeneous rock. Some excellent examples are potholes that have been carved into the thick Pennsylvanian sandstones that form the bed of the Youghiogheny River at Ohiopyle State Park in Fayette County. Sevon (1989) provided a good example of potholes formed in Mesozoic diabase in the bed of the Susquehanna River in Lancaster County. Numerous other examples could be cited as well.

Potholes formed in roads and those in streambeds are quite different features, however, both in terms of geometry and in how they were formed. Road-surface potholes form as a result of our climate and our heavy road use. Although asphalt and concrete road surfaces appear to be solid, they actually are quite porous. Water can seep rapidly into the road material if it is damaged or poorly constructed, collecting in the pore spaces between the aggregate grains. During winter, when the water freezes, the ice expands, pushing the aggregate grains apart and creating some excess space in the pores. When the ice melts, there is room for more water, which then freezes, pushes, and melts, allowing more water to enter. As the cycle continues, pushing the road surface apart from the inside out, the battering-ram action of vehicle tires destroys what is left of the cohesive strength of the road material. The asphalt or concrete falls apart and–*voila*–a pothole.

Streambed potholes, on the other hand, form primarily through the action of erosional forces in the stream. Freeze-thaw might have a part in the process by weakening the rock slightly, but the main formative agent, as Sevon (1989, p. 6) pointed out, is "hydraulic vortices created by turbulence during high-velocity flow." A hydraulic vortex is essentially an underwater tornado in which water rotates rapidly, drawing sediment in at the base and expelling it upward to the top of the vortex. Sediment grains suspended in the water act like sandpaper on the rock at the bottom of the vortex and begin scouring a depression. As the depression deepens through time, the sand scours the sides of the hole as well. The point of vortex formation, and therefore of pothole formation, occurs where the rock is weaker, such as at the intersection of joints or, in a sandstone, where the grains of the rock are not well cemented.

Some unusual potholes currently are forming in the bed of Pine Creek where the water flows over a sandstone shelf near the intersection of Pa. Route 8 and Saxonburg Boulevard in Shaler Township, Allegheny County, just north of Etna (Figure 1). The stream vortices are carving out the potholes at the intersections of numerous joints, just as they do in many other streams. What makes these potholes different is that, although they are being carved by natural hydraulic processes, they originated through human-generated explosions.

PINE CREEK FLOOD CONTROL PROJECT. Pine Creek flows in a large loop, an incised meander, that curls back and forth under Pa. Route 8 at Underhill (Figure 1). This loop outlines a spur of thick, resistant, well-developed Buffalo sandstone (Pennsylvanian, Conemaugh Group, Glenshaw Formation) that at one time projected northeastward as far as the word Undercliff on Figure 1. The railroad shown on the map runs along the hillside on the west side of the creek and through a tunnel cut into the sandstone at the spur. The spur had been partially breached on its southeastern side during construction of a large warehouse early in this century, and it was removed completely on the northeast side of Pa. Route 8 prior to construction of the Shaler Plaza shopping center (the large buildings at the word Underhill in Figure 1).

Pine Creek is prone to flooding in most of its drainage area during heavy rains, particularly at Undercliff, where the near-tortuous nature of the stream channel forced floodwaters out of the streambed and up over the surrounding flat lands. To remedy this situation, in 1986 the Commonwealth's Bureau of Flood Protection Projects constructed a diversion channel across the near end of the loop in order to expedite the flow of water away from the most flood-prone areas, yet limit the amount of damage to aquatic life. They accomplished the first objective by demolishing the warehouse, breaching the rock spur (Figure 2), and constructing a 550-foot-long levee along the eastern bank of the diversion channel to contain the water. They accomplished

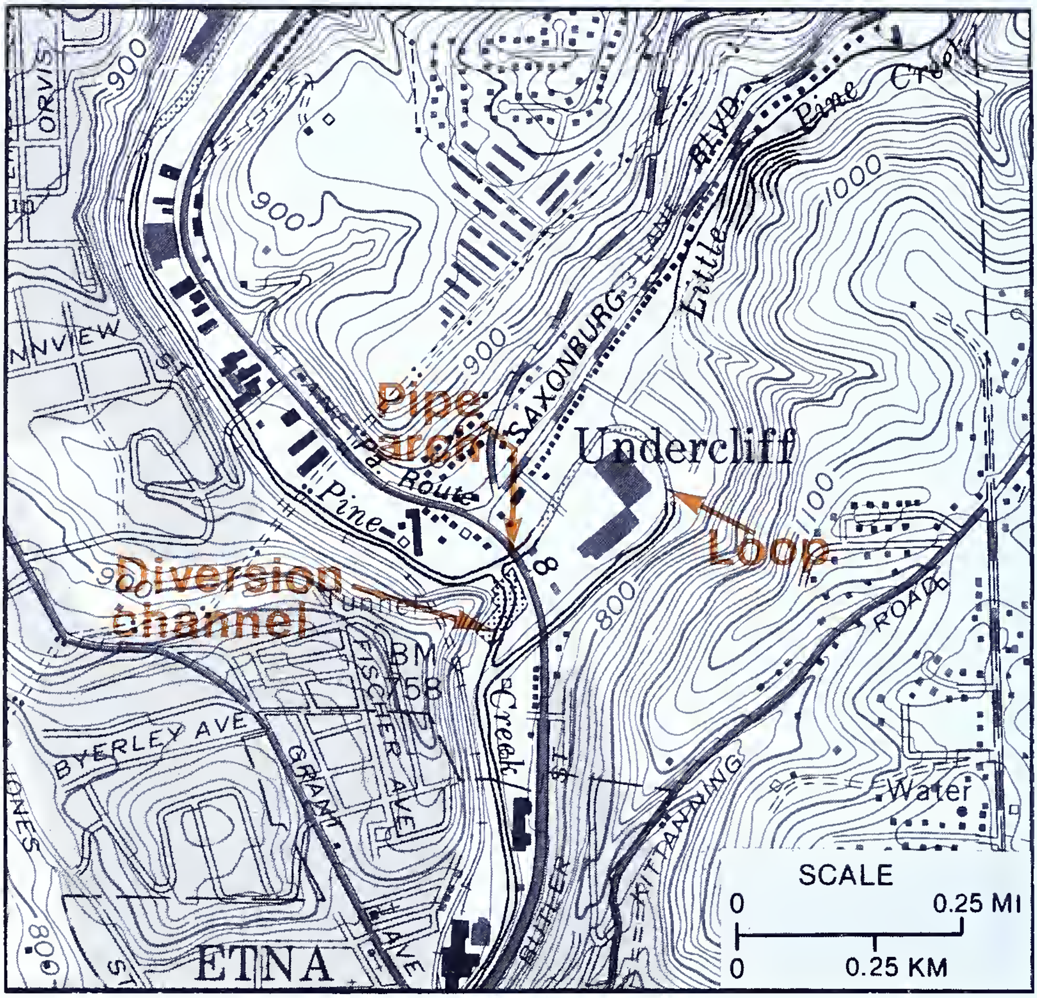

Figure 1. Location of the Pine Creek flood-control project in Shaler Township, Allegheny County, Glenshaw 7.5-minute quadrangle.

the second objective by leaving a weir (low dam) of sandstone partially blocking the diversion channel, thus maintaining the water level in the loop by allowing continuous water flow through a pipe arch beneath Pa. Route 8. The potholes occur on the surface of the weir.

POTHOLE CITY (SUBAQUEOUS). The diversion channel was constructed by blasting and digging through the rock spur. Explosive charges were set in holes bored into the rock and detonated to make rock removal easier. The detonations created radiating fractures (induced joints) that extend into the weir (Figure 3).

Potholes such as that shown in Figure 4A began forming where the induced joints in the rock created points at which water vortices formed during high-flow periods. In 1989, when I initially visited this site, most of the holes were relatively small, having a diameter not

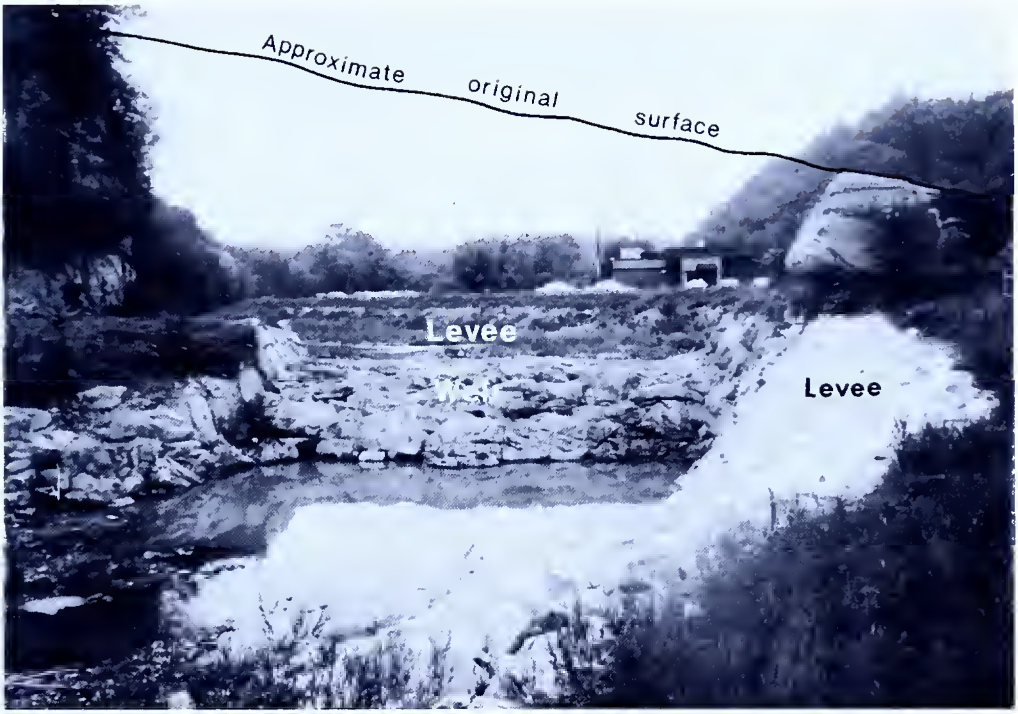

Figure 2. Excavated diversion channel of Pine Creek showing the weir, riprap-covered levee upstream, and a grouted riprap wall to prevent erosion downstream. The approximate original surface on the former Buffalo sandstone spur has been drawn in for reference. The potholes occur in the upper surface of the weir.

much larger than 6 or 8 inches and commonly less than 4 inches deep. Additionally, many of the fractures radiating from the shot holes, although showing signs of scouring (Figure 4A), did not appear to be especially susceptible to stream erosion.

Five years later, in 1994, I revisited the site and was amazed at how much scouring had taken place. The cover photograph and Figure 4B illustrate the extent of scouring that has occurred in a very short time. Figure 4B, in particular, shows that the pothole in Figure 4A had been widened to about 24 inches and deepened significantly, to about 20 inches. The volume of a typical pothole had been enlarged a whopping 4,400 percent, from about 200 cubic inches to about 9,000 cubic inches (5.2 cubic feet) in just 5 years! That is an average erosion rate of approximately 3.2 inches per year (an 880 percent increase in volume per year). In addition, the surrounding rock has been scoured to the point where many of the formerly subdued surface features of the streambed now stand out in high relief. Erosion seems to have affected the rock associated with the radiating fractures most heavily. These probably are growing through the combined actions of being hammered

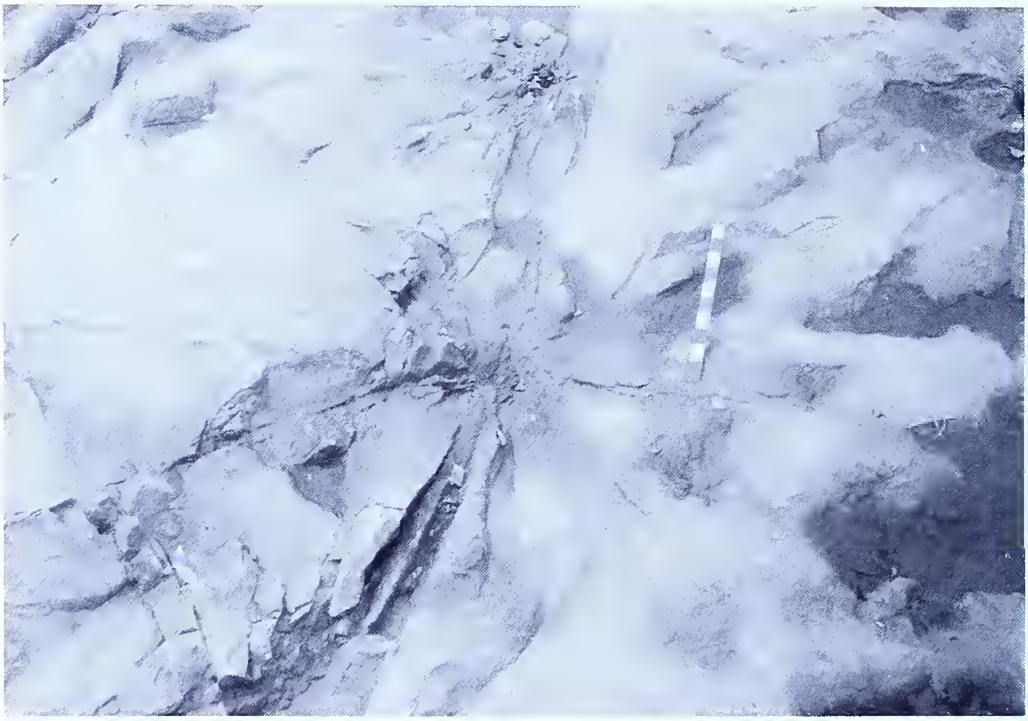

Figure 3. Shot hole in the bed of Pine Creek created during the Pine Creek flood-control project in 1986. The scale is 1 meter in length. The view is southeast across the diversion channel. Notice the radiating joint pattern typical of explosive fracturing. This photograph was taken in 1989; the photograph on the cover shows the same feature 5 years later.

by debris carried in the water column and having loose material plucked and carried away by the stream. Although the main erosional agent might be different, the relative smoothness of angles and surfaces attests to the effects of "sandpapering," the same type of scouring that creates potholes.

QUE SERA, SERA. All of this erosion might result eventually in the sort of exotically sculpted bedforms discussed by Sevon (1989). On the other hand, it might result simply in wide holes and smooth troughs in the sandstone. It will be interesting to return to the Pine Creek diversion channel in 5 or 10 years to review the progress of pothole development and erosive sculpturing in the weir. Will the potholes continue to grow deeper and wider during spring floods, or will the scouring completely change the sculpted form of the joints and their intersections? Will the joint planes widen, becoming smoother as they channel grit-laden water across the weir? Will Pine Creek become the home of exotically sculpted sandstone? Only time will tell, and Pine Creek has all the time in the world.

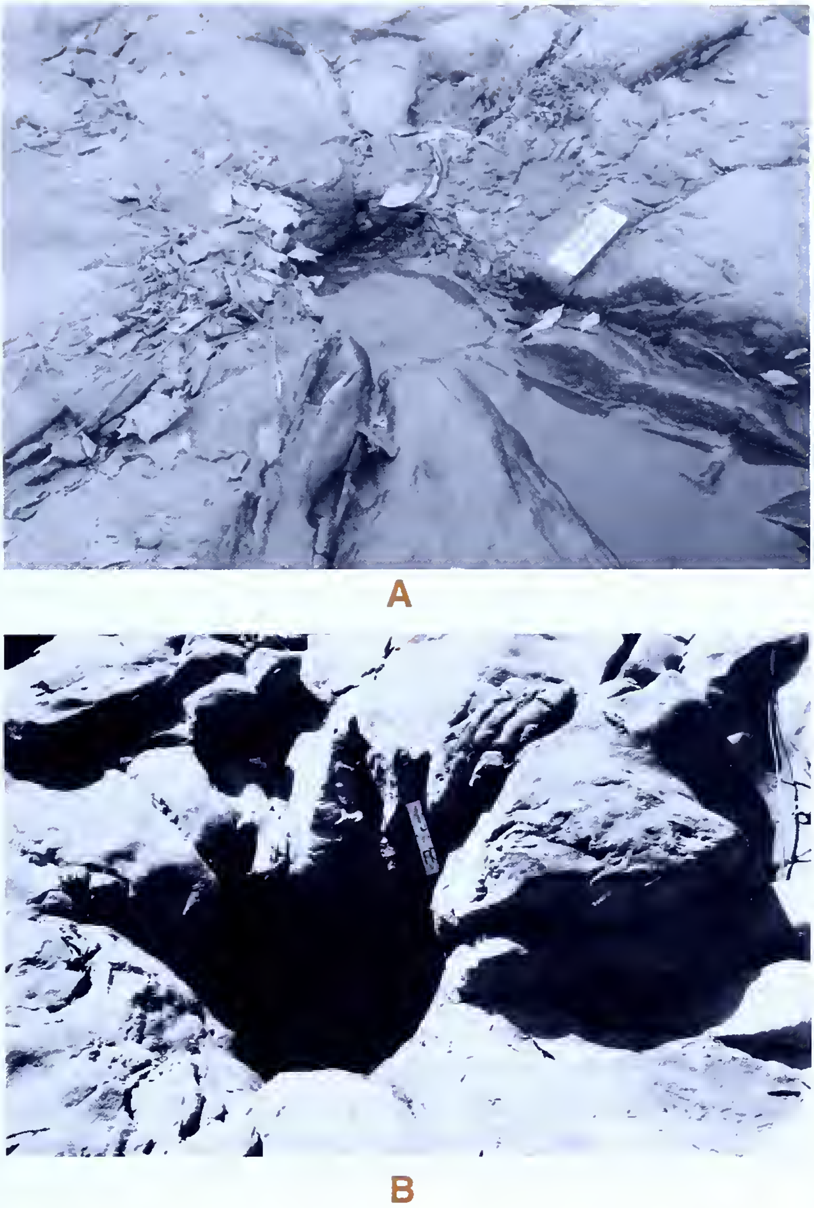

Figure 4. Close-up of a shot hole in the process of being sculpted into a pothole in the bed of the excavated channel of Pine Creek. Upstream is toward the lower right-hand corner. A. Scouring has begun to deepen and widen the shot hole, and the surrounding rock is relatively smooth. The photograph was taken in 1989. The scale is 4 inches (10 cm) long. B. The same hole 5 years later. Erosion of the streambed has increased significantly, and the hole has more than tripled in size in all dimensions. The scale is 6 inches (15 cm) long.

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Sevon, W. D., 1989, Exotically sculptured diabase: Pennsylvania Geology, v. 20, no. 1, p. 2–7.

Open-File Report on Warren County Bedrock Geology Issued

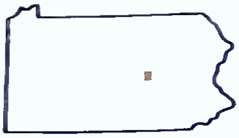
A new open-file report on the bedrock geology of Warren County, northwestern Pennsylvania, has been released by the Pennsylvania Geological Survey. The report is a consequence of bedrock geologic mapping that was undertaken in support of a groundwater-resource investigation of Warren County by the Pennsylvania Geological Survey, in cooperation with the U.S. Geological Survey, Water Resources Division.

Open-File Report 95–02 consists of two plates. The first, entitled **Bedrock Geologic Map of Warren County, Pennsylvania,** was prepared by staff geologists Clifford H. Dodge and Albert D. Glover. The bedrock geology is subdivided into 12 units, including rocks of Devonian, Mississippian, and Pennsylvanian age, and is compiled on the Warren County topographic base map (1:50,000 scale). Lithologic descriptions of map units are given on the plate. The second plate, entitled **Structure-Contour Map of Warren County, Pennsylvania,** is by Clifford H. Dodge and also includes the same topographic base map. The structure contours are on two datums, which are excellent key horizons—the base of the Warren First sand for the northern third of the county and the top of the main bench of the Corry Sandstone or equivalent top of the Corry Sandstone and Knapp Formation, undivided, for the southern two thirds of the county. The structure-contour interval is 20 feet.

Recent geologic investigations and mapping in Warren County have resulted in much greater understanding of the regional lithostratigraphic framework, vertical and lateral variability of bedrock units, and regional structure, and have lead to recognition that the major buried valleys are deeper than previously believed.

See page 15 for information on ordering. The prepaid copying and shipping costs are $5.00 plus $0.30 state sales tax for Pennsylvania residents.

Freeburg Quadrangle Open-File Report



The Pennsylvania Geological Survey announces the availability of Open-File Report 95–04, **Bedrock Geology of the Freeburg 7½′ Quadrangle, Snyder County, Pennsylvania,** by David B. MacLachlan, Donald M. Hoskins, and Dorothy F. Payne. Located in the heart of the Ridge and Valley province, the Freeburg quadrangle is underlain by Early Silurian to Late Devonian sedimentary rocks that are folded into one major anticline and one major syncline. The report consists of the following: (1) a one-color (black) photocopy of a 1:24,000-scale geologic map depicting the outcrop pattern of 23 stratigraphic units (Tuscarora Formation to Sherman Creek Member of the Catskill Formation) and showing selected structural attitudes, and (2) a separate text, which includes a description of the mapped formations and members. Considering that the geologic structure depicted on the map is not complex, but exhibits many largely unfaulted folds of differing amplitudes and wavelengths in easily traceable stratigraphic units, the report could serve as an excellent teaching tool in an introductory structural geology class.

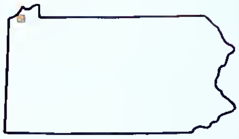
See page 15 for information on ordering. The prepaid copying and shipping costs are $3.00 plus $0.18 state sales tax for Pennsylvania residents.

Sinkholes and Karst-Related Features of York and Adams Counties

Two new open-file reports, **Sinkholes and Karst-Related Features of Adams County** (Open-File Report 95–05) and **Sinkholes and Karst-Related Features of York County** (Open-File Report 95–06), have recently been released by the Pennsylvania Geological Survey Compiled by staff geologist William E. Kochanov, they are part of a series of county-based reports that relate to sinkhole occurrences in Pennsylvania. Each report includes a brief explanatory text and copies of 7.5-minute-quadrangle maps (1:24,000 scale). The methods used in compiling the report are described in the text, which also includes references, a listing of sinkholes and their coordinates, and a glossary. The maps show the locations of karst surface depressions, sinkholes, surface mines, cave entrances, and carbonate bedrock geology.

See page 15 for information on ordering. The prepaid copying and shipping costs are as follows: **Adams County report, $15.00 plus $0.90 state sales tax** for Pennsylvania residents; and **York County report, $25.00 plus $1.50 state sales tax** for Pennsylvania residents.

Edinboro North Quadrangle Open-File Report



The Pennsylvania Geological Survey announces the availability of **Open-File Report 95–07**, **Bedrock Geology of the Edinboro North 7½′ Quadrangle, Erie County, Pennsylvania,** by Jeffrey J. Gryta, Dale Tshudy, and Joseph Lichtinger. Located near the edge of the Glaciated Pittsburgh Low Plateaus physiographic section in northwestern Pennsylvania, the Edinboro North quadrangle is underlain by nearly flat lying sedimentary rocks of Late Devonian age (Girard Shale to Venango Formation). The report consists of the following: (1) a 1:24,000-scale geologic map depicting the outcrop pattern of eight rock units (including two distinctive fossiliferous intervals) and indicating the locations of numerous local structural anomalies (i.e., "pop-up" structures and bedding-plane and low-angle thrust faults); (2) two plates depicting 17 stratigraphic sections measured along various stream courses in the quadrangle; (3) a plate showing a north-south geologic cross section of the quadrangle (vertical scale exaggerated); and (4) a separate text that includes a description of the mapped rock units and discussions of the fossils, sedimentary environments, and geologic structures characteristic of the area. All plates are one-color (black) photocopies. The report was prepared by Edinboro University professors and students, who investigated the area under a cooperative mapping contract with the Pennsylvania Geological Survey. Significant discoveries of skeletal remains of the giant Devonian fish *Dunkleosteus* that were made during this mapping project will be described in a future issue of *Pennsylvania Geology.*

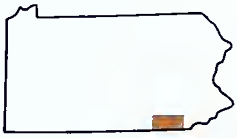
See page 15 for information on ordering. The prepaid copying and shipping costs are $7.00 plus $0.42 state sales tax for Pennsylvania residents.

Military Geology Open-File Report

The Pennsylvania Geological Survey announces the availability of Open-File Report 95–08, **Military Geology of the Richmond and Petersburg National Battlefield Parks, Virginia,** by Jon D. Inners, Brant E. Inners, and David M. Sayre. The well-illustrated, 75-page report is a revised and expanded version of a guidebook prepared for a field trip held in conjunction with the 37th Annual Meeting of the Association of Engineering Geologists, Williamsburg, Va., October 2, 1994. Included with a detailed geologic and historic road log are stop descriptions and geologic maps at Chimborazo Hill, Drewry's Bluff, Petersburg Battlefield, The Crater, Forts Harrison and Johnson, and Cold Harbor. Particular attention is paid to the engineering contributions of Colonel Henry Pleasants of Pottsville, Pa., in the excavation of the Union mine detonated prior to the disastrous Union assault at The Crater in July 1864.

Copies of Open-File Report 95-08 can be obtained for $5.00 plus $0.30 sales tax for Pennsylvania residents. Please see page 15 for information on ordering.

Surficial Materials in Parts of York, Lancaster, and Chester Counties



The Pennsylvania Geological Survey has released as open-file reports eighteen 1:24,000-scale geologic quadrangle maps of the surficial materials in York, Lancaster, and Chester Counties. These maps are one-color (black) photocopies of original compilations and are accompanied by a common 22-page explanatory text.

OF 96-01 **York quadrangle, York County**

OF 96-02 **Red Lion quadrangle, York County**

OF 96-03 **Safe Harbor quadrangle, York and Lancaster Counties**

OF 96-04 **Conestoga quadrangle, Lancaster County**

OF 96-05 **Quarryville quadrangle, Lancaster County**

OF 96-06 **Gap quadrangle, Lancaster County**

OF 96-07 **Glen Rock quadrangle, York County**

OF 96-08 **Stewartstown quadrangle, York County**

OF 96-09 **Airville quadrangle, York and Lancaster Counties**

OF 96-10 **Holtwood quadrangle, York and Lancaster Counties**

OF 96-11 **Wakefield quadrangle, Lancaster County**

OF 96-12 **Kirkwood quadrangle, Lancaster and Chester Counties**

OF 96-13 **New Freedom quadrangle, York County** (Pennsylvania part only)

OF 96-14 **Norrisville quadrangle, York County** (Pennsylvania part only)

OF 96-15 **Fawn Grove quadrangle, York County** (Pennsylvania part only)

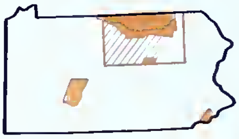
OF 96-16 **Delta quadrangle, York and Lancaster Counties** (Pennsylvania part only)

OF 96-17 **Conowingo Dam quadrangle, Lancaster, York, and Chester Counties** (Pennsylvania part only)

OF 96-18 **Rising Sun quadrangle, Chester and Lancaster Counties** (Pennsylvania part only)

The new open-file reports can be purchased individually **(one map plus explanatory text) for $2.50**, or in multiples **(two or more maps plus one explanatory text) for $2.00 each, plus 6 percent state sales tax** for Pennsylvania residents. Please see page 15 for information on ordering.

New Geologic Maps Are Open Filed by Pennsylvania Geological Survey



Five new multicolor geologic maps have been published by the Bureau of Topographic and Geologic Survey and are available for purchase. These multicolor maps will eventually accompany texts that are currently in press. When printed, the texts will be joined with the maps and distributed through the Commonwealth's standard marketing outlet, the State Book Store. In the meantime, the maps are available from the Bureau. In the list below, the costs include state sales tax and shipping. Please see page 15 for information on ordering.

Atlas 144cd, Plate 1 and Plate 2—**Bedrock and Surficial Geologic Maps of the Allenwood and Milton Quadrangles, Union and Northumberland Counties, Pennsylvania** (scale 1:24,000); Plate 3—**Mineral Production Map** (scale 1:48,000). Cost $15.10 (multicolor plates and envelope). The two geologic maps include text descriptions of the mapped geologic units, plus a brief description of their groundwater-resource potential as aquifers, their mineral-resource potential, and their foundation stability. The mineral production map shows locations of quarries, borrow pits, and mine adits.

Environmental Geology Report 9, Plate 1—**Landslide Susceptibility in the Williamsport 1- by 2-Degree Quadrangle** (scale 1:250,000). Cost $2.50 (two-color plate). The map shows areas of high, moderate, and low landslide susceptibility in the quadrangle by shades of blue on a two-color topographic base map.

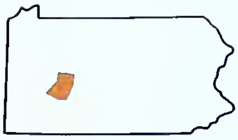
Water Resource Report 66, Plate 1—**Geologic Map of Delaware County, Pennsylvania, Showing the Locations of Selected Wells** (scale 1:50,000). Cost $9.75 (multicolor plate only). The plate includes very brief text descriptions of the mapped geologic units and their water-bearing properties.

Water Resource Report 67, Plate 1—**Geologic Map of Cambria County, Pennsylvania, Showing the Locations of Selected Wells and Springs** (scale 1:50,000). Cost $8.20 (multicolor plate and envelope). This geologic map includes brief descriptions of the mapped geologic units, well yields, and water quality.

Water Resource Report 68, Plates 1A and 1B—**Surficial Geologic Map of Major Glaciated Valleys of Bradford, Tioga, and Potter Counties, Pennsylvania, Showing Locations of Wells, Test Holes, and Data-Collection Sites** (scale 1:100,000). Cost $9.60 (two-color plate [on two sheets] and envelope). The plate includes descriptions of the mapped surficial materials and their water-bearing properties. Several enlarged area maps and numerous hydrogeologic cross sections are included as inset diagrams.

Upon request, tabular information concerning the wells located on the maps for Water Resource Reports 66, 67, and 68 (plus additional wells entered in the Bureau's water-well database after the maps were completed) is available as printouts or on disks. When photocopied, the tables require up to 100 pages. Please call 717–783–7256 for specific copying and digital media costs.

Coal Resources of Indiana County Now Available for Ordering on Open File



Coal Resources of Indiana County, Pennsylvania (Open-File Report 96–19), previously open filed in 1992 for inspection only (see *Pennsylvania Geology,* v. 23, no. 1), is now available for ordering on a quadrangle-by-quadrangle basis. Each of the compilation maps has been reduced to 1:48,000 scale (approximately 11 by 14 inches). Copies may be purchased for 25 cents per map, plus 6 percent sales tax for Pennsylvania residents. The following list shows the number and type of maps available for each quadrangle.

Maps Available in Open-File Report 96–19

7.5-minute quadrangle	*Separate maps available*[1]	*Number of maps*
Avonmore	SC, CL, Sew, Red, Pit, UFre, UKit	7
Barnesboro	SC, CL, UFre, LFre	4
Blairsville	SC, CL, Pit, UFre	4
Bolivar	SC, CL, Pit, UFre, LFre, UKit, MKit, LKit, Brk	9
Brush Valley	SC, CL, Mah, UFre, LFre, UKit, MKit, LKit	8
Burnside	SC, CL, UFre, LFre, UKit, MKit, LKit, Cln, Brk	9
Clymer	SC, CL, UFre, LFre, UKit, MKit, LKit, Brk, Mer	9
Colver	SC, CL, LFre, LKit	4
Commodore	SC, CL, Duq, UFre, LFre, UKit, MKit, LKit, Brk	9
Dayton	SC, CL, UFre, LFre, LKit	5
Elderton	SC, CL, UFre, UKit	4
Ernest	SC, CL, UFre, UKit	4
Indiana	SC, CL, UFre, LFre, LKit	5
Marion Center	SC, CL, UFre, LFre, UKit, MKit, LKit	7
McGees Mills	SC, CL, UFre, UKit, MKit, LKit, Cln, Brk	8
McIntyre	SC, CL, Pit, UFre, UKit, MKit	6
New Florence	SC, CL, UFre, LFre, UKit, MKit, LKit, Brk	8
Plumville	SC, CL, UFre	3
Punxsutawney	SC, CL, UFre	3
Rachelwood	SC	1
Rochester Mills	SC, CL, UFre, LFre, UKit, MKit, LKit, Brk	8
Saltsburg	SC, CL, UFre, LFre, UKit	5
Strongstown	SC, CL, UFre, LFre, UKit, MKit, LKit	7
Valier	SC, CL, UFre, LFre	4
Vintondale	SC, CL, LFre, LKit	4
Wilpen	SC	1
	Total	146

[1] SC, structure-contour map; CL, crop-line map of all major coal seams. Other abbreviations refer to separate maps showing crop lines and mined-out areas of the following coals: Sew, Sewickley; Red, Redstone; Pit, Pittsburgh; Duq, Duquesne; Mah, Mahoning; UFre, Upper Freeport; LFre, Lower Freeport; UKit, Upper Kittanning; MKit, Middle Kittanning; LKit, Lower Kittanning; Cln, Clarion; Brk, Brookville; Mer, Mercer.

How to Order Open-File Reports

The open-file reports described on pages 8 through 14 may be purchased by mail from the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. Please refer to the individual announcements for the cost of each report. Prepayment is required. Please make checks payable to *Commonwealth of Pennsylvania*, and be sure to include state sales tax where applicable. The reports may be examined in the library of the Pennsylvania Geological Survey, Evangelical Press Building, Second Floor, 1500 North Third Street, Harrisburg.

For further information on any of the open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–787–6029.

ANNOUNCEMENT

Internet Distribution List for Survey Announcements

The Pennsylvania Geological Survey is creating an Internet distribution list through which we will send you information concerning new or revised/reprinted publications and open-file reports, upcoming meetings and field trips, availability of surplus topographic maps, and so forth. If you wish to be included on this list, please send your Internet address to **inners.jon@a1.dcnr.state.pa.us.** It is anticipated that the first such announcements will be transmitted in April or May. The distribution list will be updated as new or revised addresses are received.

In addition, the Survey is developing a home page for access through the Internet's World Wide Web. If you have any suggestions on information you would like to see distributed through either of these media, please send your suggestions to **hoskins.donald@a1.dcnr.state.pa.us.**

State Geologist's Editorial *(continued from page 1)*

page 16) of each of the 881 7.5-minute topographic maps of Pennsylvania. These will be available to you in 1996 as a partnership-developed product of the "old" Survey in the "new" DCNR.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Digital Orthophoto Quarter-Quadrangles and Digital Raster Graphics

The U.S. Geological Survey recently announced the availability of the first black-and-white digital orthophoto quarter-quadrangles (DOQ's) and color digital raster graphics (DRG's) on CD–ROM for Pennsylvania. All of these digital products except the DOQ's for Lebanon and Clinton Counties were produced by the U.S. Geological Survey in cooperation with with the Pennsylvania Geological Survey.

A DOQ is a digital raster image made by scanning an aerial photograph and removing the displacements caused by the terrain and the camera. The features on the rectified image are in their true geographic positions. The DOQ's produced for Pennsylvania are accurate at a scale of 1:12,000 and cover 3.75 minutes of latitude by 3.75 minutes of longitude (one quarter of the area covered by a standard 7.5-minute topographic quadrangle map). The file size of one DOQ can be up to 55 Mb. Each CD–ROM contains all of the individual DOQ's included in one county. The 10 counties currently available are shown on the location map on the back cover.

A DRG is a scanned color image of a paper copy of a U.S. Geological Survey 7.5-minute topographic quadrangle map (scale 1:24,000) that has been georeferenced (i.e., distortion has been removed) using the 2.5-minute ticks on the map for control. The scanned image has been converted to an 8-bit color TIFF (tagged image file format) file. The size of the files is typically between 5 and 15 Mb. DRG files are now available on CD–ROM for the five 1-degree by 1-degree areas (64-quadrangle blocks) shown on the back cover.

Because of the spatial accuracy of DOQ's and DRG's, they can be used as layers in geographic-information-system (GIS) applications and in other software applications that accept raster images. They may be used as foundation layers over which other digital data can be overlaid and manipulated, and also as reference layers for the revision and/or creation of other digital coverages.

The cost for each CD–ROM is $32.00, plus $3.50 for each order mailed, regardless of the quantity of discs in the order. Order from U.S. Geological Survey, Information Services, Box 25286, Denver, CO 80225, telephone 303–202–4700. Prepayment is required; please make checks payable to *U.S. Geological Survey.*

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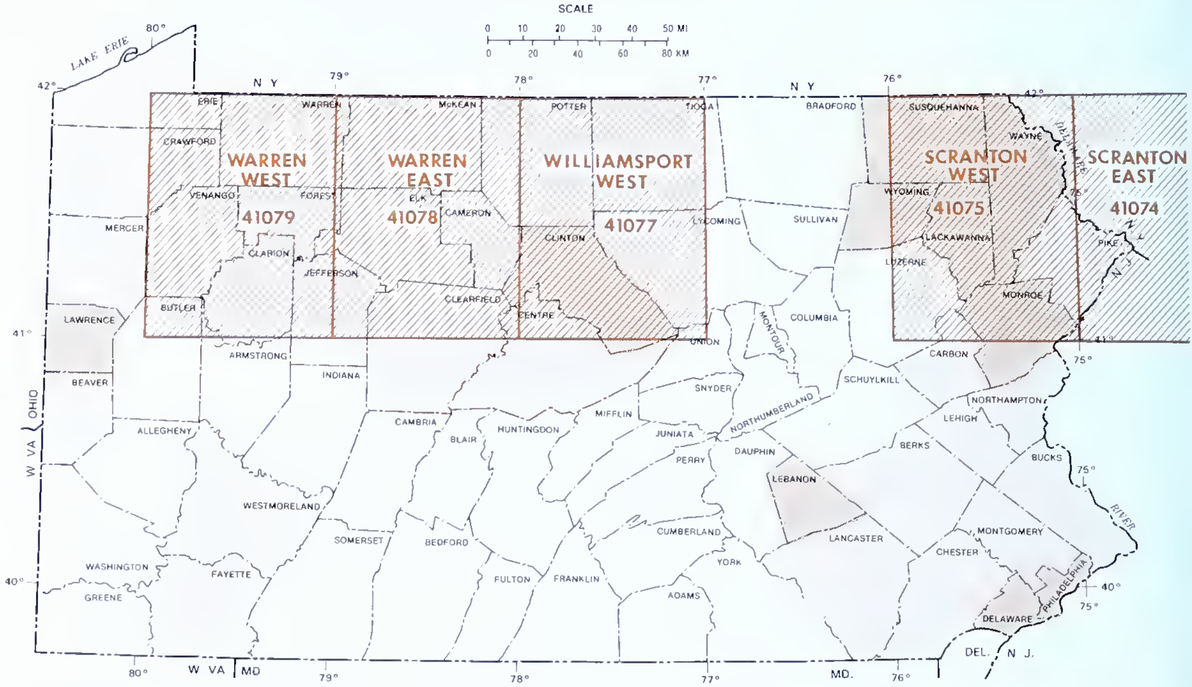
IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING

STATUS OF DIGITAL ORTHOPHOTO QUARTER-QUADRANGLES AND DIGITAL RASTER GRAPHICS IN PENNSYLVANIA

(See article on page 16)



EXPLANATION

▨ Area (1- by 1-degree) for which digital raster graphics are available on CD–ROM (Scranton East area extends to 74°W longitude). Digital raster graphics for the remainder of the state are in progress.

▩ County for which digital orthophotography is completed and available on CD–ROM

☐ County for which digital orthophotography is currently in progress

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VOL. 27, NO. 1

Pennsylvania GEOLOGY

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CONTENTS

Living with the available earth 1
Geology—Past, present, and future 2
Earth science teachers' corner—New booklet explains the important relationship between geology and everyday life 6
Almost (but not quite) heaven—Fall Run Park 8
New releases 15
  Geological research in Pennsylvania, 1994–95 15
  Westmoreland and Indiana Counties identified as prime areas for development of methane energy resources 15
  Coal-quality dataset available on CD–ROM 16

ON THE COVER

The main waterfall on Fall Run, Fall Run Park, Shaler Township, Allegheny County (see article on page 8). The waterfall is developed on the Buffalo sandstone, a unit in the Glenshaw Formation of Pennsylvanian age. Photograph by J. A. Harper.

PENNSYLVANIA GEOLOGY

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Contributed articles are welcome; for further information and guidelines for manuscript preparation, contact D. M. Hoskins at the address listed above.
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VOL. 27, NO. 1 **SPRING 1996**

STATE GEOLOGIST'S EDITORIAL

Living With the Available Earth

For geologists and others who daily deal with investigation or management of earth or land resources, Earth Day is Every Day. This slogan, from an earlier year, is intended to express the important concept that all people need to care for the earth every day, so as to keep it a hospitable place to live. Yet we find it advantageous to focus on a single day of the year to emphasize our need to act and to implement our care. One of the three special focuses for the 1996 celebration of Earth Day is planning for the future. Geologic knowledge is crucial to such planning.

We all live with the available earth, the earth that is here and now. Geologists interpret the history of the earth from its inception, over 4 billion years ago. We also describe our available earth and, from our interpretations and description, forecast changes that will occur. The geologic features we describe now are only a moment in a geologic picture that changes through time.

We formerly thought that the impact of people on natural geologic processes was negligible and that future changes would occur in similar geologic measure as in the past. Now we know that the continued growth of population, combined with expanded use of the earth's surface, is having rapid, direct, and measurable effects that formerly were the result of long-term natural geologic processes.

To adequately plan for the future, people must understand geologic processes that continually change our available earth. Some of these processes are described in the article "Geology—Past, Present, and Future." As a specific example of good planning, the geologic and modern development features described in the article about Fall Run Park provide insights for understanding available earth areas that are not suitable for modern development and should be preserved as natural areas. However, for all of this good planning, unless such sites are protected from the effects of adjoining development, they will be degraded.

Our available earth is all we have. Understanding geology will guide us in its care.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

GEOLOGY
PAST, PRESENT, and FUTURE

by Robert C. Smith, II, and John H. Barnes
Pennsylvania Geological Survey

"The present is the key to the past" has been a key concept used by geologists in interpreting their field observations since it was first proposed by the pioneering Scottish geologist James Hutton in 1785. It is a reminder to geologists that, by studying modern geologic processes, we can understand what went on in the past to create the features that we find preserved in ancient rocks. This concept is not much different than the "history repeats itself" concept of historians, who usually deal with events that occurred hundreds of years rather than hundreds of thousands or hundreds of millions of years ago.

An approximately 500-year-old Eastern Hemlock (*Tsuga canadensis*), Pennsylvania's state tree, awes visitors to the Alan Seeger Natural Area, Huntingdon County, with its beauty, size, and age. Yet its height is only about three tenths of one percent of the depth of the deepest point in the ocean, and its age is one ten-millionth the age of Earth. (Photograph reprinted by permission of Halfred W. Wertz and M. Joy Callender, authors, *Penn's Woods, 1682–1982*, Haverford House, Wayne, Pennsylvania.)

Taken together, these concepts suggest that Earth will, at times, be a scary place in the future.

How scary? Not as scary as in its earliest days. Drawing again upon analogy with human history, although basic processes have not changed and are destined to be repeated, many details have changed with time. When the Sun was new, much debris cluttered the space around it. Some of that debris coalesced to form the planets, including Earth, but many thousands, if not millions, of small fragments were left to circle the Sun. In its earliest days, Earth was something of a target, colliding with debris that circled the Sun in orbits that intersected that of Earth. In doing this, Earth swept out a path through space so that giant meteorite impacts should no longer be of immediate concern to us. After all, it has been 65 million years since the last really big collision occurred, perhaps spelling doom for the dinosaurs and clearing the way for mammals. The most significant collision between Earth and another body in recorded history, one that flattened forests around Tunguska, Siberia, in 1908, was very minor by comparison—only a hit from a cosmic snowball with the energy of 10 million tons of TNT.

As Earth has matured, some other scary things have also become much less of a threat than they were when Earth was younger. About 2 billion years ago, there was enough naturally occurring fissionable uranium on Earth to cause the reactions that take place today only in the controlled environment of nuclear reactors to take place in nature. At Oklo, Gabon, on the west coast of equatorial Africa, the remnants of such a natural reactor can be observed. Thanks to millions of years of radioactive decay, there are no longer natural concentrations of fissionable uranium. Similar radioactive decay has allowed Earth's internal heat engine to run down to the point that volcanic activity has decreased. The destruction of life by volcanoes over an area of more than 100 square miles is now unlikely in any given decade, but in the distant past such eruptions were common. Fears of meteorite impacts, natural nuclear reactors, and volcanoes will not interfere with our celebration of Earth Day 1996.

But is all well with our mature "Mother Earth"? Not necessarily. Without any help from man, and despite the over 4 billion years that Earth has had to settle down, earthquakes such as those at New Madrid, Mo. (1811, magnitude greater than 7), and Charleston, S. C. (1886, magnitude greater than 6), will continue to occur. They will be infrequent, but even with present technology there will be no warning. At present, we cannot even do a very good job of predicting *where* east-coast earthquakes will occur.

In 1972, the Pennsylvania Geological Survey underwent a soggy but educational experience when its headquarters was flooded.

Floods! You say Pennsylvania has had enough once-in-500-year, once-in-200-year, and once-in-100-year floods in the last 25 years? Well, we agree. Our soggy experience at the Pennsylvania Geological Survey's former headquarters on a floodplain during the 1972 flood that accompanied tropical storm Agnes was educational but not satisfying. But more floods will come, and there is nothing sacred about a 200-year-old record book on a 4.5-billion-year-old planet. Do you know if you are living on an area that receives once-in-10,000-year floods? Do you know the depth to the water table beneath your property? How much that water table fluctuates? Whether you are in a landslide-prone area? Whether you live in a limestone or dolomite sinkhole-prone area? This is not intended to be a commercial for the Fearmonger Shop, as "advertised" by humorist Garrison Keillor on his radio program, *A Prairie Home Companion*. It is just a reminder, as we pause to pay respect to our home planet on this Earth Day, that the geological processes that have shaped and modified Earth are guaranteed to continue, and that they will occasionally be destructive.

What does the future hold for an Earth dominated by mankind? There will be more landslides and sinkholes than would otherwise be the case because we have a constant need to rearrange the landscape so that we can construct buildings and highways to accommodate an ever-increasing population. Many of these landslides and sinkholes are preventable, but not all will be prevented. Better news coverage in the electronic era will spread news of sinkhole collapses and call attention to municipalities that employ poor storm-water management plans, thus providing disincentive for further development in such places.

Floods downstream from dikes and levees will be more severe than they would be if there were no dikes or levees, but government-run facilities such as the Raystown Dam will ameliorate effects in some basins. Catastrophic dam failure, such as in Johnstown in 1889 and 1977, will become less frequent because generations of horror-stricken visitors to the Johnstown Flood National Memorial will learn from history and will demand independent dam inspections.

Periodic droughts have occurred in the past and are guaranteed to occur again in any part of Pennsylvania except the part under Lake Erie. This should suggest that continued groundwater investigations are in the “essential,” not just in the “it would be nice” category.

The composition of the atmosphere and the climate have varied dramatically over Earth’s 4.5-billion-year history, but the rate of change has typically been extremely slow. Are we now creating a risk of catastrophic change by burning fossil fuels? We do not know, but we would not want to be living in Pennsylvania without access to such fuels, especially not after the frigid Januarys of ’94 and ’96! For most of us, the risks of living near well-designed and independently monitored nuclear power plants are acceptable. However, few of us can afford to pay to build more such plants, and fewer still are keen on flooding all of our river valleys to build more hydroelectric dams or covering half of the state with opaque photovoltaic cells to capture solar energy.

A potential risk associated with the burning of fossil fuels comes from the liberation of carbon dioxide into the atmosphere. If the atmosphere contained too much carbon dioxide, heat that normally is radiated into space would become trapped in the atmosphere. With time the heat might build up, resulting in changes in climate and the permanent flooding of coastal areas as the polar ice caps melted. Some scientists suggest that Earth has natural mechanisms that correct for such changes in the composition of the atmosphere. One such mechanism is the removal of excess carbon dioxide through the formation of additional deposits of limestone, which is made up partly of the elements in carbon dioxide. Other scientists maintain that the process of limestone formation could be too slow to protect us from rapid changes in the atmosphere.

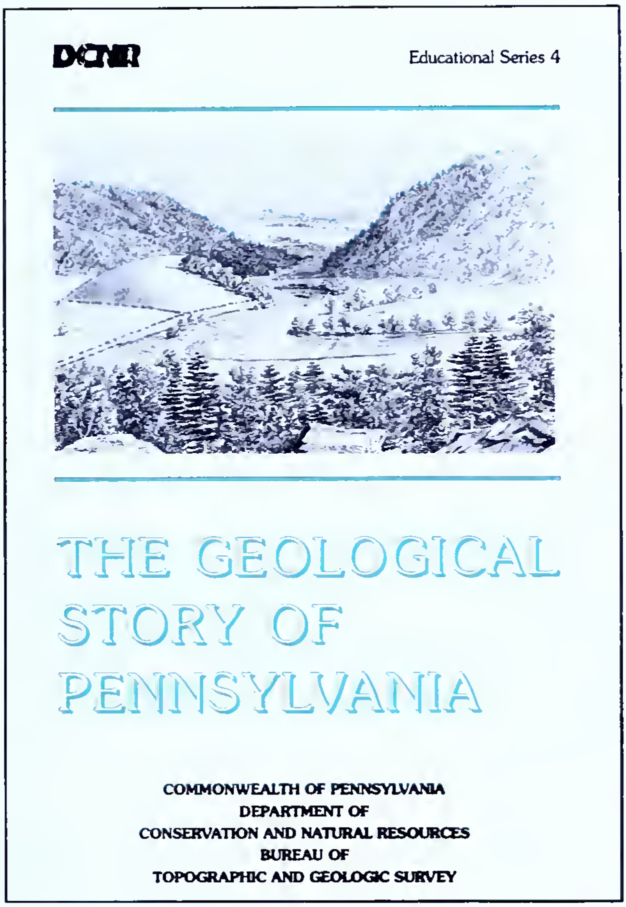
Although many studies that scientists undertake sound strictly academic, they can have important practical applications. The study of the process by which limestone forms is clearly one of these. Another, which is related, is a careful worldwide study of the circulation and temperature of the oceans. The oceans, collectively, are the greatest reservoir of heat that drives the weather and affects climate, yet very little is known about their thermal properties. Meanwhile, practical considerations require us to continue to identify sources of fossil fuels and groundwater, and to use existing resources wisely.

On this Earth Day, we pause to think of the many ways in which Earth's natural processes affect us. Geology has taught us that Earth has changed and will continue to change. Through further geological investigations we can learn what the processes of change are, how they have affected life on Earth in the past, and how they are likely to do so in the future. Our studies will always lead to more questions and still more studies, but it is only through this process we can learn to better adapt to the forces that continually act to shape our planet.

EARTH SCIENCE TEACHERS' CORNER

New Booklet Explains the Important Relationship Between Geology and Everyday Life

The Pennsylvania Geological Survey is pleased to announce the printing and availability of a new edition of Educational Series (ES) 4, **The Geological Story of Pennsylvania.** First published in 1935 and titled *Pennsylvania Geology Summarized*, this popular booklet was revised minimally during the 55 years of its wide use before it went out of print. Because the purpose of the booklet is to provide students, teachers, and other interested persons with readable basic geologic information and to explain how it is related to Pennsylvania, ES 4 has been totally rewritten in an effort to bring it up-to-date with current geo-



Educational Series 4

THE GEOLOGICAL STORY OF PENNSYLVANIA

COMMONWEALTH OF PENNSYLVANIA
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logical concepts and to make it easier to read and understand.

Such a revision was necessary because of the development since 1935 of many new geological concepts. These concepts have led to a better understanding of the geology of Pennsylvania and have improved our ability to apply our knowledge to practical situations, ranging from mineral extraction to environmental cleanup. Probably the most important of these new concepts is the theory of plate tectonics. According to this theory, the continents are not stationary platforms, but are continually moving around the surface of the earth. Application of this theory to previously poorly understood observations has clarified many aspects of Pennsylvania geology, such as how the rocks of the Ridge and Valley province were folded into anticlines and synclines.

The booklet, expanded from 17 to 44 pages, is divided broadly into three sections: an introductory section in which some of the principles of geology are explained, a central narrative section covering the geologic history of Pennsylvania from the origin of the earth to the present, and a concluding section in which the important relationship between geology and everyday life is discussed. Educational Series 4, **The Geological Story of Pennsylvania,** by John H. Barnes and W. D. Sevon, is available free of charge in classroom quantities to teachers and in single copies to individuals by contacting the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105-8453, telephone 717–787–2169.

Almost (but Not Quite) Heaven— FALL RUN PARK

by John A. Harper
Pennsylvania Geological Survey
Judith E. Neelan
Pennsylvania Department of Environmental Protection

WILDERNESS IN THE 'BURBS. Urban parks commonly are little slices of near wilderness that refreshingly coexist with skyscrapers and subways, hospitals and hotels, cathedrals and concrete. Some parks are mowed, trimmed, and weeded as immaculately as a golf-course fairway, whereas others literally allow the citizenry to experience nature in the wild. Central Park in New York City is probably the best known of these in North America, but all major, and many minor, cities have at least one.

Suburban areas also have parks, again ranging from the well-kept garden to the preserved natural ecosystem. One small park in Allegheny County, just north of Pittsburgh, is an interesting amalgam of nature and suburban-sprawl eyesore. The natural aspects of Fall Run Park outweigh the eyesores, creating a fortunate bit of paradise that suffers from the ailments of overdevelopment. In the spring, you can combine recreation with learning as you admire the trillium, jack-in-the-pulpits, and other wildflowers while studying a leaking dump or the effects of poor stormwater management.

Fall Run Park is located in Shaler Township adjacent to Glenshaw (Figure 1), 7 miles from downtown Pittsburgh. Besides the requisite sports facilities (ballfields at the upper and lower ends of the valley), this long, narrow park (Figure 2) also boasts a nature trail approximately 1 mile long that weaves back and forth across Fall Run. Much remains of the natural beauty of western Pennsylvania, including the waterfalls that give the main stream, and thus the park, its name. Additionally, visitors will discover a variety of interesting geological features, including rock exposures, stream deposits, fossils, a prehistoric rockfall (site D in Figure 2), several environmental and geotechnical problems and, near the southern end of the park, a small natural gas seep in the bed of Fall Run (site A in Figure 2) where methane often can be seen bubbling up through the water.

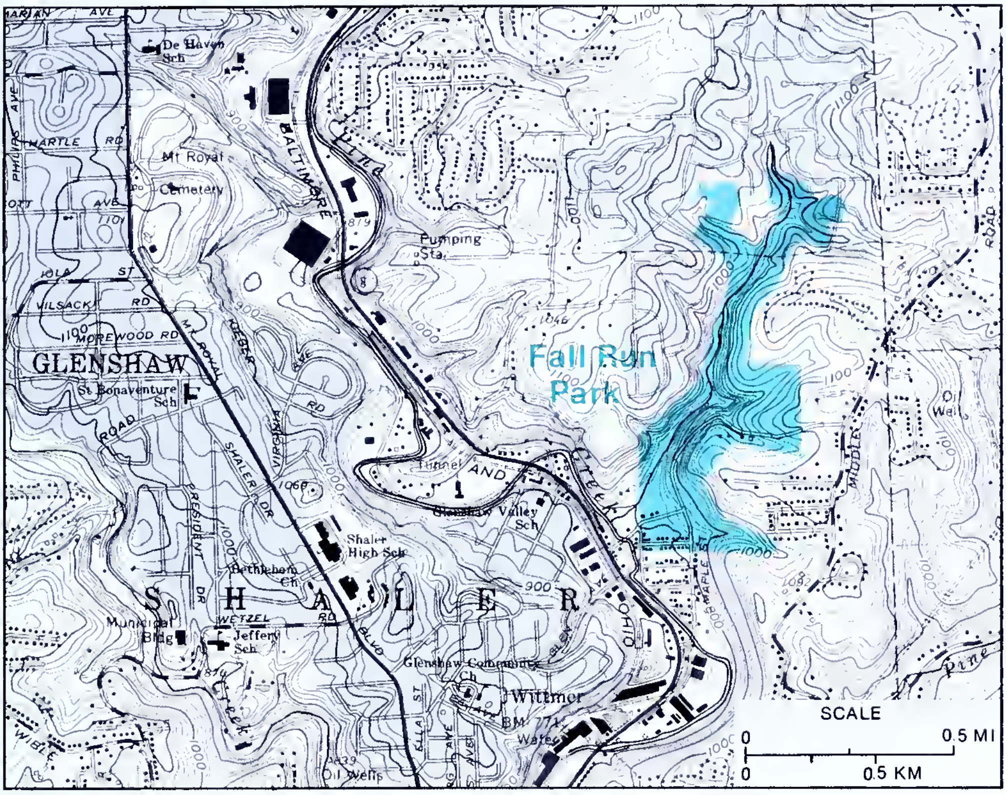

Figure 1. Portion of the Glenshaw 7.5-minute topographic map showing the location of Fall Run Park in Shaler Township, Allegheny County.

WHERE CREEKS RUN WILD (APPROXIMATELY). Fall Run Park occupies about 90 acres of a relatively steep sided valley. The average relief is approximately 130 feet, but in places it exceeds 200 feet with slope gradients exceeding 50 percent. Fall Run valley is approximately 1 mile long and 1,200 to 1,500 feet wide, and contains four major tributaries and several minor ones. The hallmark of this wonderful valley, a waterfall about 35 feet high (see front cover), is on Fall Run just north of the midpoint of the park (site E in Figure 2) and separates the park into two distinct parts. The valley above the falls is broad and U-shaped, has a grass-carpeted valley floor averaging 100 feet wide, and has forested valley walls sloping at approximately 20 degrees. The valley below the falls, in contrast, is canyon-like, has a narrow valley floor averaging 50 feet wide, and has steeply sloping, rugged, often barren walls. The stream gradient is 180 feet per mile.

OF ROCKS, WATERFALLS, AND ANCIENT ANIMAL TRACES. The bedrock underlying Fall Run Park ranges through most of the Glen-

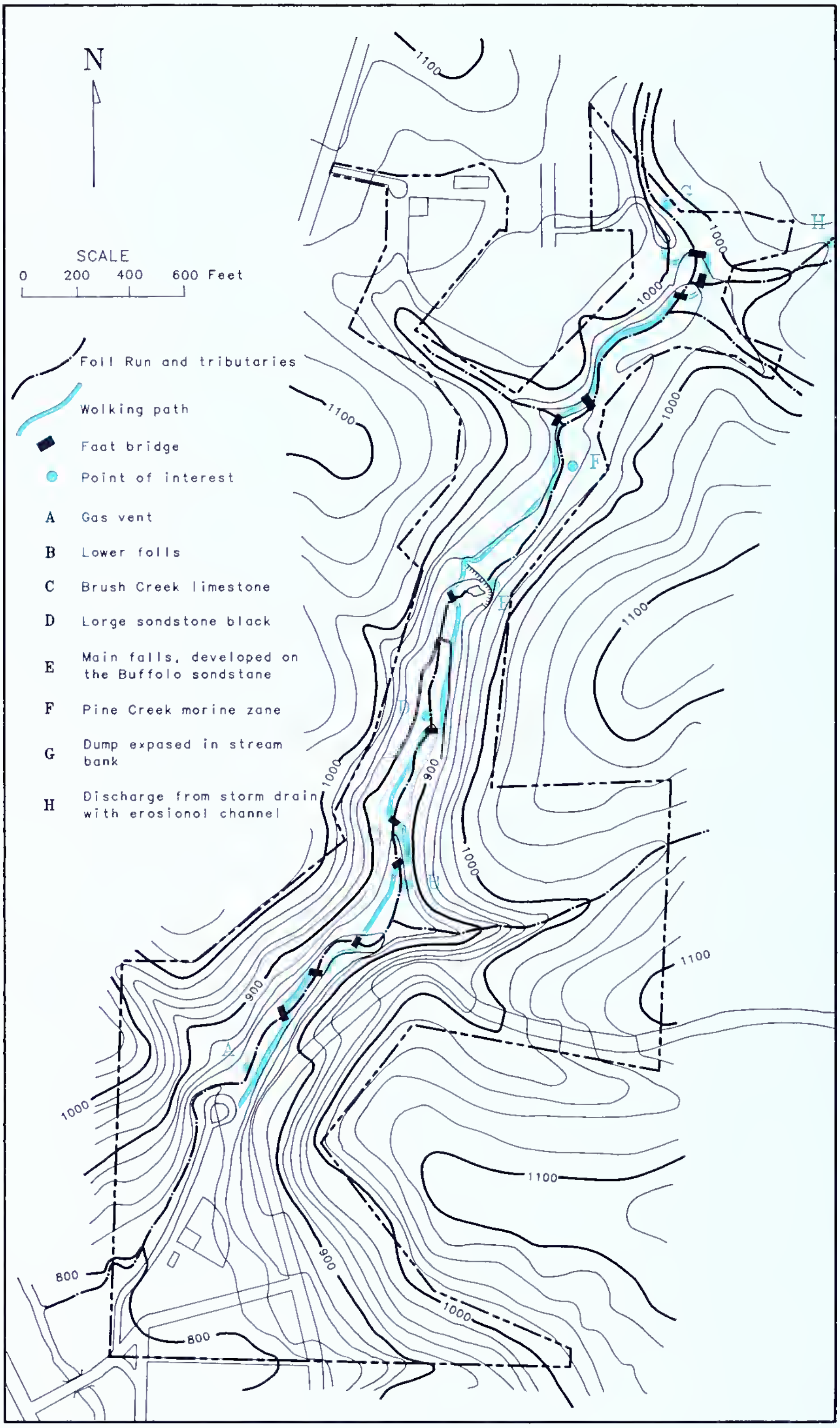

Figure 2. Topographic map of Fall Run Park showing locations of features of interest (modified slightly from Shultz and others, 1995, p. 3–17, Figure 3–4).

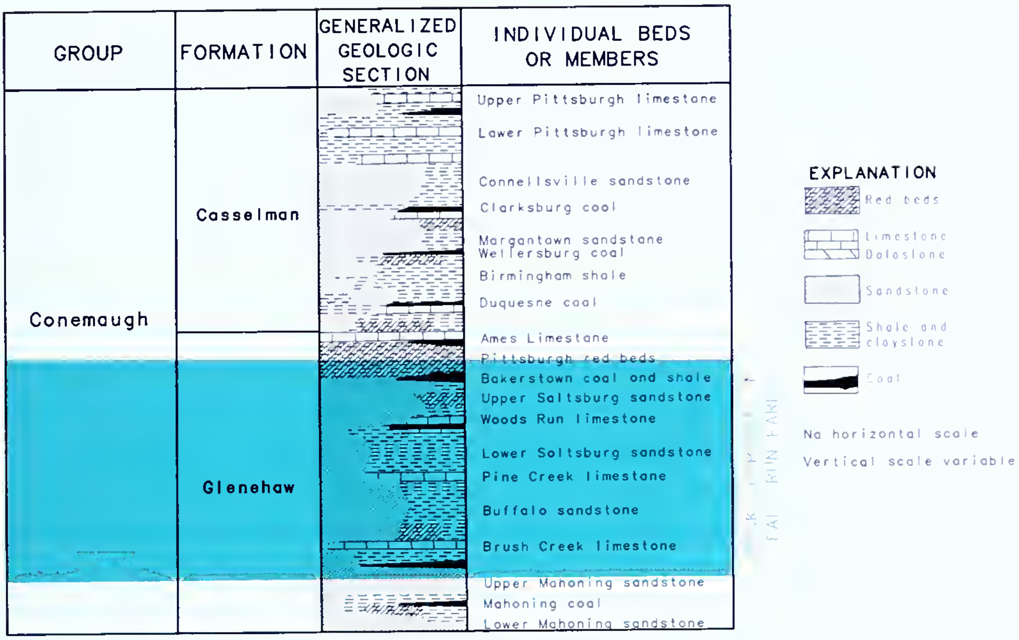

Figure 3. Generalized stratigraphic section of the Conemaugh Group in western Pennsylvania. Fall Run Park spans part of the Glenshaw Formation between the Mahoning coal and the Pittsburgh red beds.

shaw Formation of the Conemaugh Group (Figure 3). Shales and fissile siltstones of the middle to upper part of the Mahoning member crop out in the creek walls at the southern end of the park, and the Pittsburgh red beds, notorious for being the major natural contributor to most of western Pennsylvania's landslide problems, can be seen at the higher elevations. The creek bed itself provides many of the better exposures as Fall Run flows over alternating stretches of stream debris and sections of smooth bedrock, typically either shale or limestone. Because the bedrock layers slope gently to the east-northeast, many of the edges of individual layers form ridgelike obstructions in the stream, creating a string of small rapids. The main waterfall, as well as others seen high on the canyon walls within the tributary channels, developed on the more resistant Buffalo sandstone.

A smaller, 8-foot waterfall (site B), situated downstream from the main falls, is developed on a hard shaly layer of the Mahoning member only a few feet below the Brush Creek limestone. A tributary just below the waterfall occupies a hanging valley. The waterfall, hanging valley, and entrenched aspect of Fall Run downstream from this point suggest the possibility that the waterfall might represent a knickpoint, an abrupt change in the stream profile.

Two fossiliferous units, the Brush Creek limestone and the Pine Creek marine zone, crop out in Fall Run Park. The Brush Creek, a dark-colored clay-rich limestone less than 1 foot thick, forms the bed of Fall Run at site C. The Pine Creek marine zone, which occurs above the main waterfall at site F, consists of brown to tan-colored limestone sandwiched between black, limy shales. Only the lower black shale is noticeably fossiliferous at this locality. Shell material, mostly a hash of fossil seashells, is common in some of the float, but it is difficult to tell which unit has the most debris. The primary fossils are trace fossils. Dark-colored *Zoophycos*, the feeding trace of a worm that swept the seafloor in a semicircular pattern, is easily distinguished against the buff-colored weathered surface of the rock. Other trace fossils noted were *Conostichus*, interpreted as the resting trace of a sea anemone, and *Beaconites*, a wide burrow made by some kind of marine animal plowing through the mud.

HERE COME DE SLUDGE, AND OTHER SUBURBAN NICETIES. One of the more noticeable aspects of Fall Run Park is the impact of humanity on the valley itself. The valley wall is ringed with houses from several stages of development, beginning in the mid- to late 1960's. The following three activities, begun at that time, continue to bedevil the valley today: (1) A sewer line was installed in the valley floor. For several years, the line has been in need of repair, as evidenced by cracks in some of the exposed sections. In addition, the system tends to overflow during thunderstorms, due to the influx of stormwater at some point in the line, leading to flooding and contamination of the creek. (2) A former dump was buried without adequate technological precautions for ensuring environmental safety. Debris can be seen in the northernmost tributary wall (site G) amid oozing patches of rust-colored leachate. (3) Surface stormwater discharges directly into the valley during heavy rainfalls.

Developers building in the area prior to passage of the Stormwater Management Act of 1974 simply funneled stormwater into drainpipes that discharged into the upper reaches of the tributaries to Fall Run. This promoted accelerated headward and lateral erosion of the tributary valleys. Houses sitting at the upper reaches of these tributaries are losing value with each passing year as erosion literally slices the land out from under them. Some effort has been made by landowners to slow the velocity and, therefore, the erosional impact of the discharge by loading the tributaries with trees, brush, rocks, and other debris. Alas, nature will undoubtedly take its course in the end, expanding the valleys into the very properties they were intended to drain.

Headward erosion represents the grand opus of overdevelopment around Fall Run Park. Two new tributaries having steep, barren, V-shaped gullies were carved at site H by the discharge of drainpipe stormwater directly onto unprotected colluvium, rather than into existing tributary channels. The larger of the two is an ugly scar roughly 8 feet wide, 5 to 13 feet deep, and 200 feet long. At its source, peeking out from beneath a well-trimmed lawn, is an 18-inch pipe that is protected by a concrete enclosure (Figure 4). The enclosure is still present, unlike other pipe enclosures in other tributaries, but it is being undermined and will eventually collapse into the gully. The discharge from this pipe has been powerful enough not only to erode the gully wall 6 feet beyond the drainpipe opening, but also to erode the gully down to bedrock about 8 feet below.

Developers building in the area after 1974 have been required by law to install sedimentation ponds that protect streams by (1) trapping sediment behind a dam so that it will not be washed away, and (2) collecting excess runoff and allowing it to drain from the pond to an established tributary at a rate less than or equal to the natural discharge rate for the area. The contrast between the older "piped" tribu-

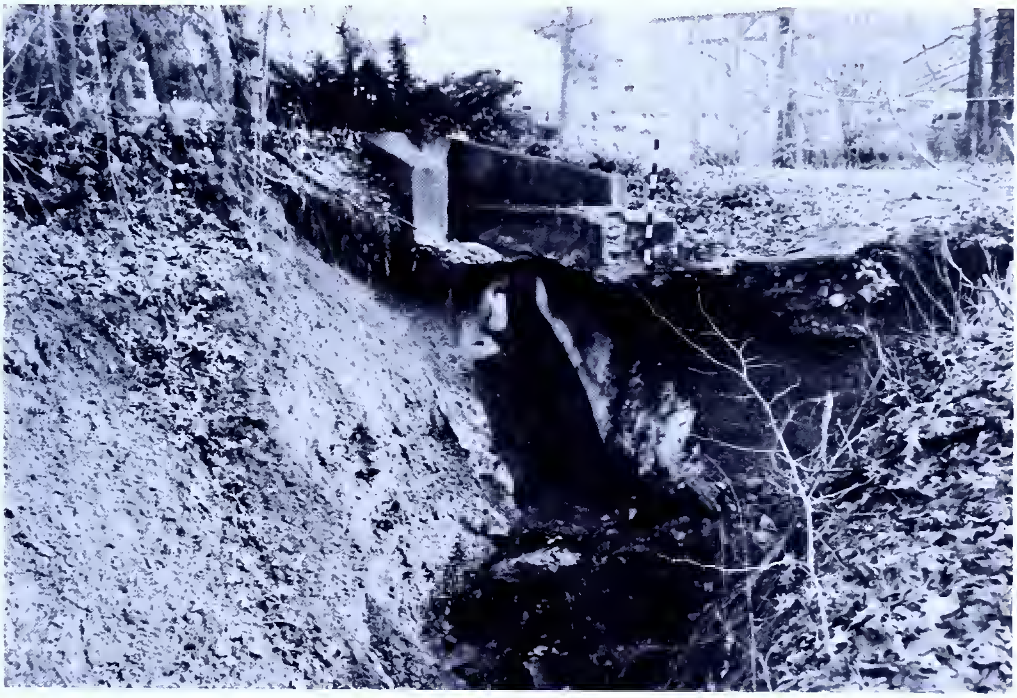

Figure 4. Approximately 25 years of man-induced runoff from the local storm-drain system has undermined the concrete enclosure and eroded a deep gully to bedrock. Scale (at arrow) is 1 meter long.

taries and the more recent "ponded" ones is remarkable. Tributaries fed with piped stormwater typically exhibit rough, craggy gullies where the bedrock is exposed, vegetation is sparse, and trees on the slopes above the gullies have been undermined. Undisturbed tributaries, or their "ponded" counterparts, appear more natural, and vegetation and forest litter cover the ground. It is unfortunate that the erosion and sedimentation laws are not retroactive—Fall Run Park could use some relief from an abundance of precipitation on too many rooftops, roadways, and residential lawns.

THE FINAL WORD? WE DOUBT IT! Visitors to Fall Run Park tend to return to it because, in spite of its environmental woes, the park offers a salve to soothe bouts of "suburbanitis." It is a place to slow down, relax, and cool the mind and body. One can play there, name the deer, or just kick back and indulge the senses. One big advantage of Fall Run Park is that it is an oft-used natural laboratory, a place to study numerous "ologies" (biology, geology, ecology, and so forth). Because changes occur so rapidly in the park, there is simply no better place in the Pittsburgh area to study the processes that shape the landscape. What may have taken nature tens of centuries to achieve in undeveloped areas is being accomplished in decades as a result of the suburban impact. Creek meanders removed in the late 1960's are reforming, prehistoric alluvial fans are being downcut, and waterfalls and valley walls are retreating at an accelerated rate.

While new-found stewards of the valley (mostly concerned Shaler Township citizens) would like to see Fall Run Park restored to its pristine state, they now battle simply to resist further negative impact. A recent plan to install another ballfield atop one of the natural tributaries has been temporarily thwarted, but yet another developer wants to tap into the already overtaxed sewer line. In spite of the scientific intrigue about how nature will respond to man's maneuvering in Fall Run, there is no doubt that this is a valley in danger of further suburban stress. And, unfortunately, there does not seem to be much to prevent it aside from the faithful efforts of concerned citizens.

REFERENCE

Shultz, C. H., Harper, J. A., and Neelan, J. E., 1995, Bedrock geology and urban geologic problems of northern Allegheny County, Pennsylvania, in Hutchinson, P. J., ed., Pittsburgh Geological Society Golden Anniversary (1945–1995) Field Guide Book: Pittsburgh Geological Society, p. 3–1—3–35.

Geological Research in Pennsylvania, 1994–95

The Pennsylvania Geological Survey recently released **Geological Research in Pennsylvania, 1994–95,** a 47-page compilation of geological research in Pennsylvania reported for the period July 1, 1994, through June 30, 1995. A listing of geological reports published during the same time period is also included. For a free copy of the report, contact the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, telephone 717–787–2169.

Westmoreland and Indiana Counties Identified as Prime Areas for Development of Methane Energy Resources

Northern Westmoreland and Indiana Counties have been identified in a new report as prime areas for targeting development of methane, a natural gas, from Pennsylvania's bituminous coal. The report is based on geological investigations conducted in seven counties in southwestern Pennsylvania and eight counties in West Virginia between 1991 and 1993 by staff of the Pennsylvania and West Virginia Geological Surveys.

The survey geologists found that some of Pennsylvania's bituminous coal layers (those included in the Allegheny Group) have the greatest potential for producing methane because of their higher coal rank.

In the new report, 31 maps, 11 cross sections, and other diagrams illustrate the distribution and thicknesses of coals and associated sandstones. Areas where repeated intervals of coal and intervening sandstone layers are "stacked" are the best target areas for exploratory drilling and production, particularly because the coal rank is higher in these areas than in other areas, and the coals have a higher methane gas content.

The 72-page publication (report number PB96–107396) is entitled **Geological Aspects of Coalbed Methane in the Northern Appalachian Coal Basin, Southwestern Pennsylvania and North-Central West Virginia** and can be ordered from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, telephone 703–487–4630. The price is $19.50 plus $4.00 for shipping and handling (for international orders, please call the number above for shipping and handling information). Please make checks payable to *NTIS*. For rush orders, call 1–800–553–6847.

Coal-Quality Dataset Available on CD–ROM

Coal-quality information useful in addressing air- and water-quality issues is now available on compact disc.

Of the 189 chemicals believed to cause adverse environmental effects—including mercury, selenium, and arsenic—14 are produced by coal combustion. The U.S. Geological Survey coal-quality database, derived from the National Coal Resources Data System, is recognized by the Environmental Protection Agency (EPA) as an independent and objective basis for setting standards relating to emission of toxic air substances from coal-combustion facilities. The complete database is made up of almost 13,000 validated samples from every major coalbed in every coal basin in the nation. Information from 7,400 of these samples is contained on the CD–ROM, including more than 800 samples from Pennsylvania. All of the samples have been analyzed for a suite of more than 90 trace elements, including all of the elements listed in the Clean Air Act amendments.

The database has been selected by the EPA for use in a study on hazardous air pollutants required by the 1990 amendments to the Clean Air Act. The utility industry and several coal-mining companies have also agreed to use this database for their estimates on hazardous air pollutant emissions.

The Coal Quality Data Base, OFR–205, is available free of charge from the U.S. Geological Survey, Branch of Coal Geology, MS 956, National Center, Reston, VA 22092. To order, please contact Linda Bragg at telephone 703–648–6451, fax 703–648–6419, or E-mail lbragg@ncrds.er.usgs.gov.

—K. Mitchell Snow, U.S. Geological Survey, Branch of Public Affairs, Office of the Director

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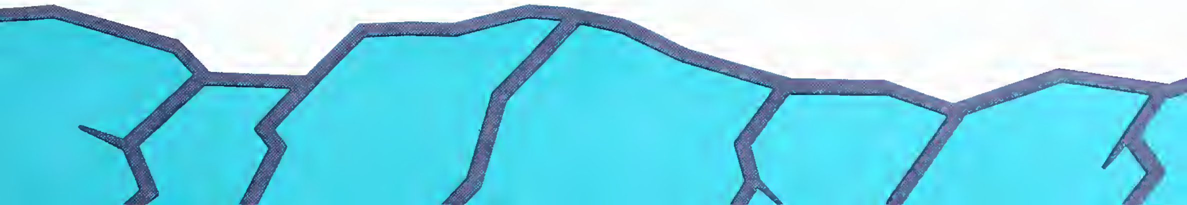

GEOLOGY AND PLANET EARTH

(See article on page 2)

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CONTENTS

Pennsylvania's parks and forests—on the "Trail of Geology" 1
From the Ice Mine to Oil Creek: touring Pennsylvania on the "Trail of Geology"—the Survey's Park Guide series 2
Geology along the "Path of Progress" in and around Canoe Creek State Park 8
Rocks, rivers, and landscapes: solving some of the geologic mysteries of Pennsylvania's state parks 12

ON THE COVER

Tilted beds of sandstone and siltstone in the Devonian Scherr Formation along the Juniata River, west end of Warriors Path State Park, Bedford County (see article on page 12). Beds are inclined approximately 60 degrees. Photograph by W. E. Kochanov.

PENNSYLVANIA GEOLOGY

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VOL. 27, NO. 2 **SUMMER 1996**

STATE GEOLOGIST'S EDITORIAL

Pennsylvania's Parks and Forests—on the "Trail of Geology"

Pennsylvania is blessed by outstanding natural and scenic features and vistas, many geologic in origin. A large number of these geologic features are preserved in our Commonwealth's state parks and forests.

Visiting Pennsylvania's state parks and forests is a common activity during the warm summer months but is much less so in other seasons of the year. Yet visiting these parks and forests during the off-season can be very rewarding, particularly if geological features are your interest. The natural sites and scenic views are less crowded and are often more scenically appealing, especially if photography is planned. The geological features, sometimes obscured or hidden by foliage (and people) during the summer, become much more evident and are easier to examine and photograph.

As part of our Department's activities in accomplishing its major initiatives, one of which is to encourage tourism by promoting our state park and forest systems, we have prepared for this issue of *Pennsylvania Geology* three articles that explain

(1) how you can obtain guides to the geology in more than 20 state parks;
(2) the geology and industrial heritage of one of our newer state parks, Canoe Creek; and
(3) the mysteries behind a few common geologic features that you may have seen or might encounter in the future in our state parks and forests.

Now is a fine time to visit and enjoy our state parks and forests! Take along a copy of Educational Series (ES) 4, *The Geological Story of Pennsylvania*, our newest free publication. If you encounter a geologic feature in our state parks or forests that you can't explain with these articles or ES 4, let us know and we will provide you with the answer to your geologic mystery.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

From the Ice Mine to Oil Creek: Touring Pennsylvania on the "Trail of Geology"—the Survey's Park Guide Series

by John H. Barnes
Pennsylvania Geological Survey

Pennsylvania's state park system is among the most extensive and accessible in the nation. State parks are located in every region of Pennsylvania and provide wonderful settings for observing and appreciating all aspects of nature, including the state's geologic wonders. The land protected by the park system includes many of the most interesting geological features of the state. In recognition of this, the Pennsylvania Geological Survey long ago began to publish a series of "Trail of Geology" Park Guides, meant to be used by park visitors so that they might be better aware of the geological features found in each park and better understand how the landscape that they are enjoying came into being (see map on back cover).

AN ICE MINE, A BOULDER FIELD, AND A POTHOLE. The Park Guide series was launched in 1969 with three fold-out brochures. Park Guide 1 covered Trough Creek State Park, in which visitors encounter the strange phenomenon known as the Ice Mine. To quote the guide, "The Trough Creek Ice Mine is not a real mine but is a short opening into the hillside. Dug, perhaps, as a prospect hole in the early days of mining, it now serves as an air duct for the release of cold air trapped during the winter in the rock mass above. . . . [I]n the springtime, outside air begins to warm . . . and dense cold air flows downhill out of the rock mass. Melting snow water enters the mine opening and freezes as it meets the flow of cold air. . . . This freezing continues well into the summer until the flow of cold air from the rock mass ceases" (Wilshusen, 1969).

Park Guide 2 introduces park visitors to the mysteries of one of the more unusual geological features of Pennsylvania, a 400- by 1,800-foot boulder field in Hickory Run State Park (Figure 1). The boulders are believed to be the product of freeze-thaw erosion of rock from nearby outcrops 20,000 years ago when the great continental ice sheet of the Wisconsinan glaciation lay nearby (Geyer, 1969). The exact mechanism by which the boulders reached their present location, many becoming polished and rounded, remains a mystery. Interpretation of evidence uncovered since Park Guide 2 was written

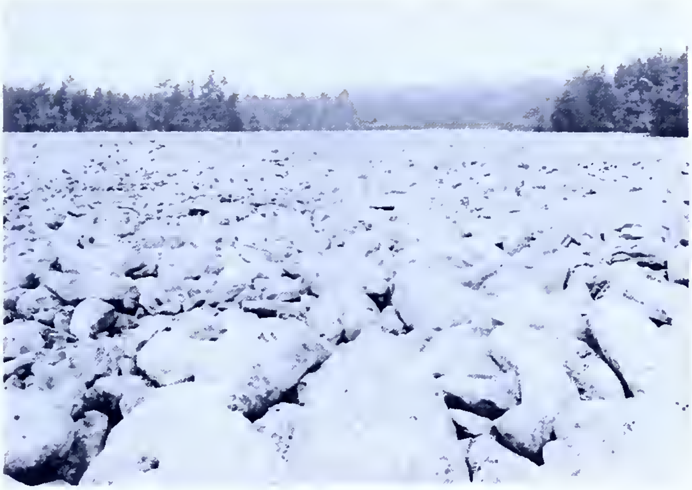


Figure 1. The Hickory Run boulder field has long fascinated visitors as they try to figure out how the boulders reached their present position. Photograph by W. D. Sevon.

raises the possibility that the boulders moved in several distinct flows, possibly in mixtures with sand and ice (Sevon, 1987).

The topic of the third of the initial offerings was a pothole, claimed to be "the largest pothole in the world." (Are you surprised that Pennsylvania should claim this honor?) The pothole, in Archbald State Park, is another feature related to the Wisconsinan glaciation. According to the Park Guide, "A surface stream flowing on a glacier probably broke through a crevasse in the ice of the glacier and fell to the bedrock located hundreds of feet below. Enough force would have been generated by the falling water to begin a whirling motion of rock fragments in an already existing small depression in the rock surface. As the rock fragments swirled and bumped each other and ground up the bedrock, they became smaller and smaller and the depression became deeper and larger. As time progressed, new rock fragments tumbled into the hole, enabling the grinding process to continue" (McGlade, 1969).

EXTENDING THE TRAIL. Of the first three of the Geological Survey's Park Guides, only the one on Hickory Run State Park is presently in print. But the Park Guide series has hardly become dormant. The series now includes 21 Park Guides, 15 of which are in print (Table 1 and Figure 2). Some Park Guide authors focused on one or two prominent features in each park; others considered the overall geologic setting of the park. Most of the Park Guides are in the form of fold-out brochures. The newest ones (20, 21, and a revised edition of 8) and future ones follow a new enlarged format—each is a 6- by 9-inch booklet containing more and larger illustrations, larger type, and suggestions for activities while visiting the park.

Pennsylvania's geology is known for its diversity, and that diversity is reflected in the Park Guides that have been added or revised in the past 12 years (Table 1).

Table 1. ***Park Guides Issued by the Pennsylvania Geological Survey***

Park Guide	Year	Park	Geologic features
1*	1969	Trough Creek	Ice Mine, Balanced Rock (erosional remnant)
2	1969	Hickory Run	Hickory Run Boulder Field
3*	1969	Archbald	Archbald Pothole (glacial feature)
4*	1970	Moraine	Glacial features (lake, esker, moraine)
5*	1971	Leonard Harrison and Colton Point	Grand Canyon of Pennsylvania
6	1987	French Creek	Diabase and historic ore deposits
7*	1971	Ohiopyle	Waterfall and gorge, rock deformation
8	1993	Valley Forge National Hist. Park	Extensive geologic record, karst features, quarry
9*	1975	McConnells Mill	Gorge, historic iron ore deposit and furnaces
10	1978	Gifford Pinchot	Diabase intrusions
11	1980	Ravensburg	Castle Rocks (erosional remnant), Big Rock Spring
12	1980	Worlds End	Loyalsock Gorge, the Rock Garden (erosional remnant), fossil lungfish burrows
13	1980	Ricketts Glen	Waterfalls, Midway Crevasse, fossil lungfish burrows
14	1980	Nockamixon	Sentinel Rock (erosional remnant), epidote crystals in quarry
15	1981	Caledonia and Pine Grove Furnace	Historic iron ore and furnace, Pole Steeple overlook
16	1982	Swatara	Fossils (brachiopods, trilobites, crinoids, gastropods, cephalopods, pelecypods, bryozoa, graptolites, starfish)
17	1983	Samuel S. Lewis	Scenic overlook of the lower Susquehanna Valley, outcrops
18	1984	Promised Land	Crossbeds, joints, glacial striations, potholes, peat bogs
19	1984	Raymond B. Winter	Ridge and Valley features, fossil worm tubes, stream piracy, springs
20	1991	White Clay Creek Preserve	Metamorphic rocks, pegmatites, valley development
21	1991	Presque Isle	Shoreline processes and features
22†		Oil Creek	Glaciation, fossils, bedrock structures, early oil exploration

* Out of print
† In press

PG 6, French Creek State Park. This park is adjacent to the Hopewell Furnace National Historic Site in southeastern Pennsylvania. The two parks preserve an important colonial settlement that grew up in proximity to minable iron ore. The ore was processed at Hopewell Furnace to allow the manufacture in colonial America of goods that might otherwise be shipped from England. The furnace operated from 1771 until 1883. Some places where the magnetite ore that fed the furnace was obtained are indicated in the Park Guide.

Park Guide 6 contains detailed descriptions of several sites in both parks. Among these is Mount Pleasure, an elongate, smoothly contoured 885-foot hill, about which are some of Pennsylvania's youngest and oldest rocks, ranging in age from 200 million years to

Figure 2. The Pennsylvania Geological Survey currently has 15 Park Guides in print.

at least 1 billion years old. The authors lead the reader through the interesting series of events that were recorded by the formation of these rocks (Inners and Fergusson, 1987).

PG 8, Valley Forge National Historical Park. Originally Valley Forge State Park, this park opened in 1893 as Pennsylvania's first state park. Similarly to French Creek, this park is located in a historic area of southeastern Pennsylvania. The historical significance of Valley Forge is familiar to everyone who has read of Gen. George Washington's encampment over the winter of 1777–78. The geological features of the park are less well known but are also interesting.

The author of this Park Guide explains the origin of the landforms found in and near the park. He also directs visitors to specific sites where geologic features can be observed in detail, revealing clues to the geologic history of the region. Among these is the Port Kennedy quarry, where rocks having an age difference of 300 million years are in contact, the older rocks tilted at an angle to the younger rocks. The remnants of ancient caves and sinkholes are also preserved in this quarry (Wiswall, 1993).

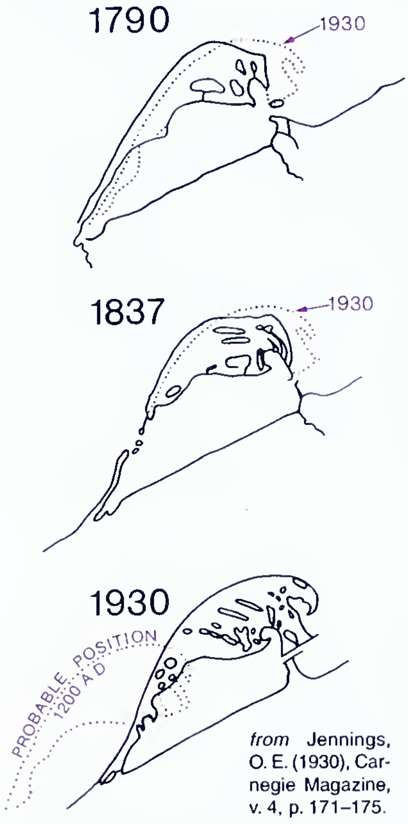
PG 20, White Clay Creek Preserve. Recalling a period in the colonial era when Pennsylvania and the three "Lower Counties" that were to become Delaware were administered jointly, this Park Guide was published jointly by the Pennsylvania and Delaware Geological Surveys. The creation of White Clay Creek Preserve was a joint venture of the two states to preserve a quiet and scenic valley in the Piedmont Upland that straddles the state line near the heavily developed Philadelphia-Wilmington area.

The author of this Park Guide makes clear the story of the origin of the landscape and of the complex metamorphic rocks that underly it. Sites where the visitor can see specific features are identified in the booklet by a special symbol and in the preserve by signs.

In addition to the geological history, this guide includes short, interesting sections on life in the White Clay Creek Valley in the past, and on errors in the surveying of the state boundaries that led to confusion at the Arc Corner, where Pennsylvania, Delaware, and Maryland were supposed to come together (Faill, 1991).

PG 21, Presque Isle State Park. From the Arc Corner we venture diagonally across the state to Lake Erie to visit a park that is unique in Pennsylvania. Presque Isle is a recurved sand spit that encloses and protects Erie Harbor. Presque Isle State Park, a major recreational resource for residents of Erie, is the most heavily visited of Pennsylvania's state parks. In this Park Guide, the author describes the combination of glacial and shoreline processes that formed Presque Isle.

The shoreline is a dynamic environment in which a fragile sand structure such as Presque Isle constantly changes (Figure 3). The author describes geological processes that can be seen operating on Presque Isle, eroding sand from one area and depositing it in another to make new land. The effects of these processes and the attempts to stabilize the peninsula are discussed (Delano, 1991).



from Jennings, O. E. (1930), Carnegie Magazine, v. 4, p. 171–175.

Figure 3. Presque Isle has changed considerably through recorded history, sometimes even becoming an island instead of a peninsula (from Jennings, 1930).

PG 22, Oil Creek State Park. The newest Park Guide, which is not yet available, covers Oil Creek State Park in northwestern Pennsylvania and focuses on two topics: the effects of glaciation on that part of Pennsylvania and the early exploration for oil. The oil industry began in Pennsylvania with the drilling of the Drake Well in nearby Titusville in 1859. Long before that, oil seeped naturally from the ground into Oil Creek and was used by Native Americans and later by settlers for medicine and for waterproofing canoes and clothing. After the success of the Drake Well, the area along Oil Creek boomed with fortune hunters seeking "black gold" (Figure 4). Remnants of this era can be found within Oil Creek

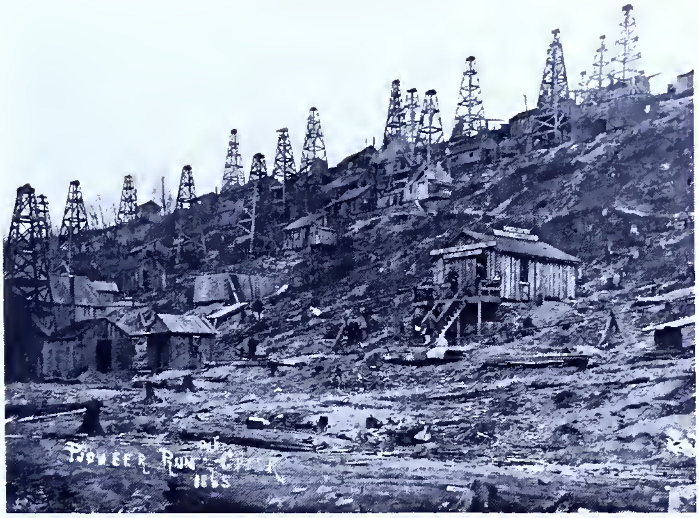


Figure 4. This area, now a part of Oil Creek State Park, was quite unparklike when this photograph was taken in 1865. It became the destination of many seeking riches after the success of the nearby Drake Well gave birth to the oil industry. Photograph from the collection of the Drake Well Museum.

State Park as well as in nearby areas such as the ghost town of Pithole City. The park is also the site of a scenic gorge and several waterfalls, the result of changes in drainage routes brought about by glaciation. This and other effects of glaciation are explained by the author (Harper, in press).

HOW DO I GET A PARK GUIDE? The Park Guides that are in print are available at the respective park offices. Copies are also available by writing to the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

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Geology Along the "Path of Progress" in and Around Canoe Creek State Park

by Robert C. Smith, II, and John H. Barnes
Pennsylvania Geological Survey

Life in any mountainous region includes special challenges to transportation, agriculture, and the manufacturing industries. To a person cruising past on the Pennsylvania Turnpike or glancing out the window of an airliner, the gentle Allegheny Mountains of Pennsylvania may not seem to impose obstacles to compare to the rugged White Mountains of New Hampshire or the Sierra Nevada of California. In the eighteenth and nineteenth centuries, though, before the era of turnpike tunnels and jet aircraft, the Alleghenies provided as much of a challenge to life as any mountain range. Yet, life in the mountains of Pennsylvania also provided opportunities. The region was rich in coal, iron ore, and limestone—raw materials that would fuel the industrial revolution in America and improve the productivity of its farms. The problem of overcoming the obstacles posed by the terrain to take advantage of the richness of the land stimulated innovative thinking that led to ingenious solutions. This spirit of innovation is celebrated by DCNR's Pennsylvania Heritage Parks Program, which has established the Allegheny Ridge State Heritage Park in this region to better tell the story of the people who built the region.

The Path of Progress Heritage Route, which was established by the Southwestern Pennsylvania Heritage Preservation Commission, is a 500-mile road link that carries travelers through several state heritage parks and past many other sites that were instrumental in the development of commerce in the Alleghenies. Some are well-established tourist attractions, such as the Allegheny Portage Railroad National Historic Site, where one can learn about an engineering triumph of the 1800's, a system to carry canal boats over the Alleghenies by way of a network of inclined planes, stationary engines, and horse-drawn cars. This system, which seems cumbersome today, was essential to the development of Pennsylvania, and for 20 years, from 1834 to 1854, it was the primary link between the eastern and western regions of the state. Although the system would not have been necessary were it not for the mountains, those same mountains were the source of building stone needed to anchor the tracks and construct the bridges and other structures that were needed to make it work (Figure 1).

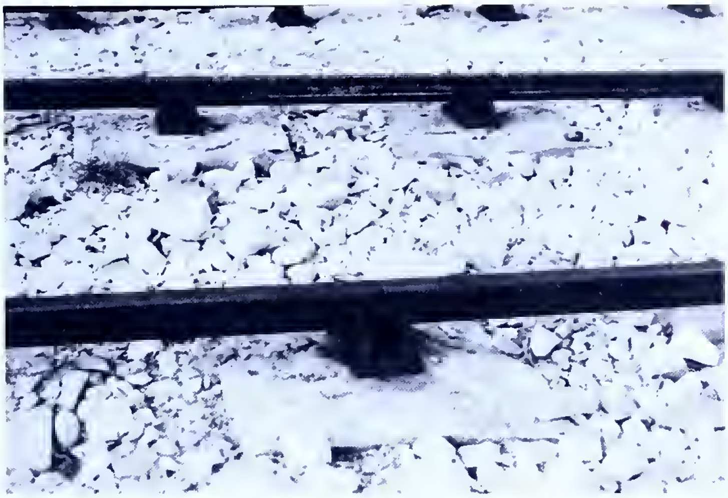
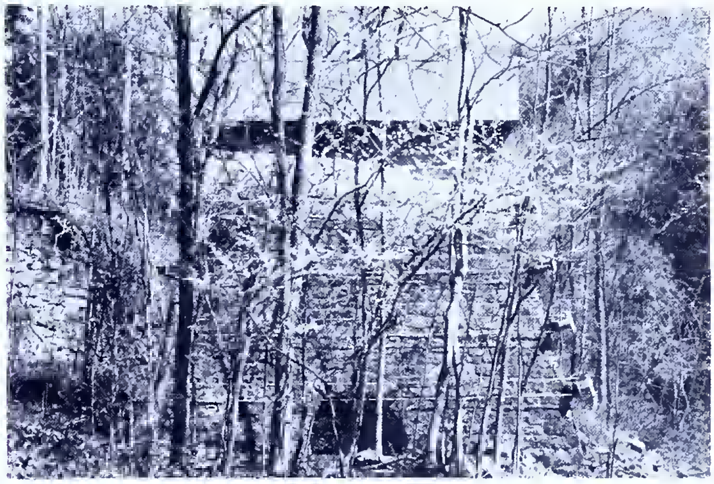


Figure 1. Instead of wooden ties, sandstone "sleepers" were required to anchor the rails of the Allegheny Portage Railroad in the steep slopes of the inclined planes used to haul canal boats over the Allegheny Mountains. The sandstone is believed to have been obtained from nearby outcrops.

Some other sites are less well established for tourism, but are nevertheless of historical importance. An example is the iron furnace at Mount Etna, Blair County, about 1 mile east of U.S. Route 22 along a dirt road. At its peak, from 1830 to 1870, this furnace could produce more than 1,000 tons of cast iron per year (Inners, 1986). Looking at the crumbling ruins of the stack (Figure 2), seemingly all but forgotten, it is hard to imagine that iron produced there was used in the construction of the U.S. Capitol Building (Sternagle, 1986).

Figure 2. The Mount Etna iron furnace stack in Blair County is now braced to prevent it from crumbling. From 1830 to 1870, it was a center of activity and produced iron used in the construction of the U.S. Capitol Building.



Nestled in the majesty of the Alleghenies is Canoe Creek State Park, yet another stop along the Path of Progress. Canoe Creek offers visitors a wide variety of recreational and educational activities. Many of these can be accomplished at the same time. For example, the park has a high-quality beach from which one can, among other things, review the mountain silhouettes and attending hawks with a minimal effort. The park offers easy to moderate trails where the interaction of geology, animals (including humans), and plant life can be observed. If you contact a state parks naturalist, you can even learn about the relation of bats to geology and underground limestone mining in this park!

On the easy Limestone Trail to the foundations of turn-of-the-century limekilns, one can observe the seeming medieval splendor of structures where limestone was once burned to produce lime (Figure 3). The builders of the foundations left the mark of their technique in the wood-grain "fossils" in cement poured against rough-cut wood forms that left a lasting impression (Figure 4). On the more difficult Moores Hill Trail, one can observe how rapidly mother nature is reclaiming abandoned limestone quarries with ferns (Figure 5). Look sharply, or you will only see the ferns, or in the right season perhaps the lime-loving orange butterflyweed attracting orange butterflies! More serious plant lovers can contrast the lime-loving flora with that on the acidic sandstone-derived soils on the same trail. Both are beautiful.

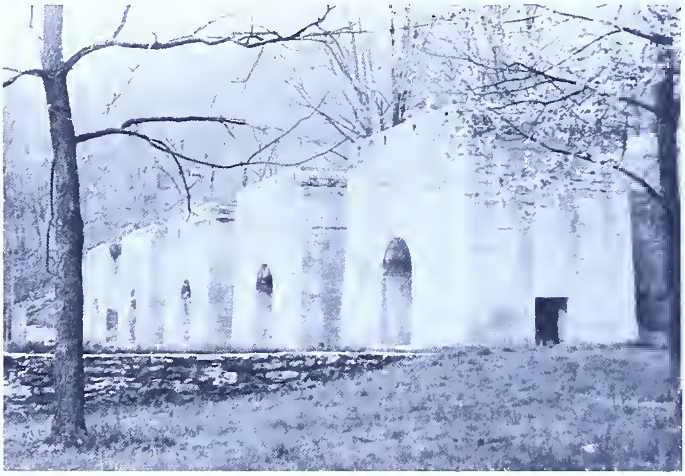


Figure 3. The foundations of the limekilns at Canoe Creek State Park have taken on an almost mystical quality as they stand in solemn tribute to those who built and operated them at the beginning of the century.

One of the most recent additions to the park is the Visitor Center, in which the role of geology, and of limestone in particular, to the development of the area is revealed. Exhibits include information on the nature of limestone, its uses, how it is found, and how it was mined and processed at Canoe Creek. These exhibits include artistically mounted samples of minerals, fossils, and rocks from the park area and larger, hands-on specimens that were provided by New Enterprise Stone and Lime Company, Inc., from a nearby quarry so that the limited outcrops in the park could be preserved. Central to the exhibits is a model of the limekiln operations (Figure 6). The model depicts the mining, burning, and transport of limestone and finished lime at Canoe Creek in detail.

Additional exhibits are concerned with Pennsylvania's geological history and the park's wildlife, including the star attraction—bats!

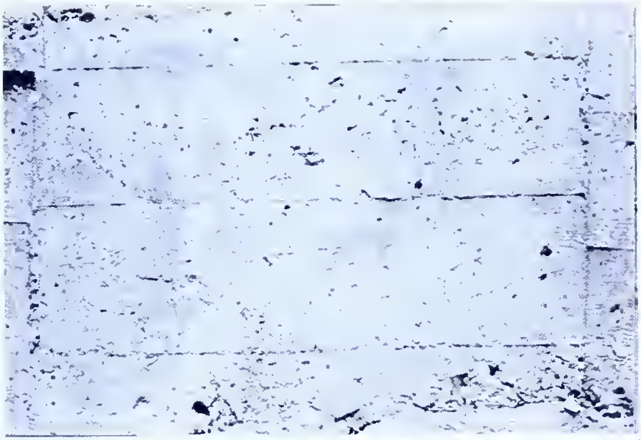


Figure 4. The wooden forms that were used to construct the limekilns at Canoe Creek State Park made a lasting impression in the concrete.

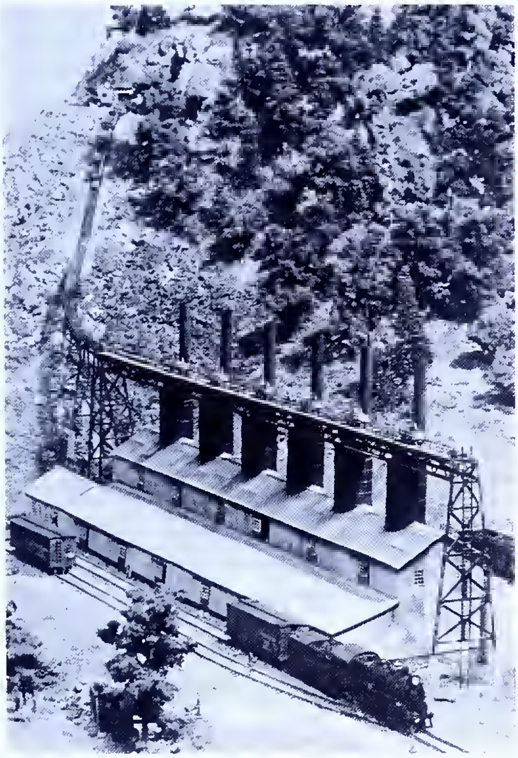


Figure 6. The past is recreated in a detailed model of the limekiln operations at Canoe Creek State Park.

Figure 5. Ferns are now taking over limestone quarries at Canoe Creek State Park.

The exhibits were prepared under contract by the design firm of Inside Outside with technical assistance from the Pennsylvania Geological Survey. Funding was obtained from the Southwestern Pennsylvania Heritage Preservation Commission. Further information on the Path of Progress or any of its attractions can be obtained by writing to the Commission at P. O. Box 565, Hollidaysburg, PA 16648–0565.

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Rocks, Rivers, and Landscapes: Solving Some of the Geologic Mysteries of Pennsylvania's State Parks

by William E. Kochanov
Pennsylvania Geological Survey

Imagine yourself as a traveler in Pennsylvania long before the convenience of paved highways or even dirt roadways. You follow the paths made by white-tailed deer along hollows studded with oak and chestnut, boat down rapid streams and lazy rivers, and scramble up rock-covered slopes to look out over the Great Valley.

You may have wondered what forces created the unique features of Pennsylvania's magnificent landscape. The answers lie in the rocks. Many of these rocks and formations can be seen and explored in Pennsylvania's state parks.

The state parks attract millions of travelers each year, who, like their early counterparts, have come to enjoy the scenery, to recreate, or to simply satisfy their curiosity. Whether it is your first visit or one of many return visits to Pennsylvania, each state park has an interesting geologic story.

The geologic story is a mystery, and, as with any good mystery, there are clues that range from the subtle to the obvious. In a geologic mystery, however, the clues can sometimes be millions of years old! Let's examine some of these clues and see what story they can tell us about the geology at some of Pennsylvania's state parks.

MYSTERY 1. Put yourself near the foot of the Blue Stone quarry at Linn Run State Park in Westmoreland County (Figure 1). As you look at the outcrop, you note the obvious, a criss-crossing pattern angling across the face of the bedrock. Can you figure out what the cross-cutting pattern indicates?

One place to look for clues is in the rock itself. Take two pieces of the rock and rub them against each other while holding them over a piece of dark paper or cloth. Small pieces of the rock will fall off. If you look at the small pieces through a magnifying glass, you will see that the small bits of rock are grains of sand, usually composed of the mineral quartz. Next, you may ask yourself, "In what present-day environment can I find sand?" Answers: the beach, a river or stream, or the desert. Using one of these environmental settings, one can piece together a story to explain the criss-cross pattern.

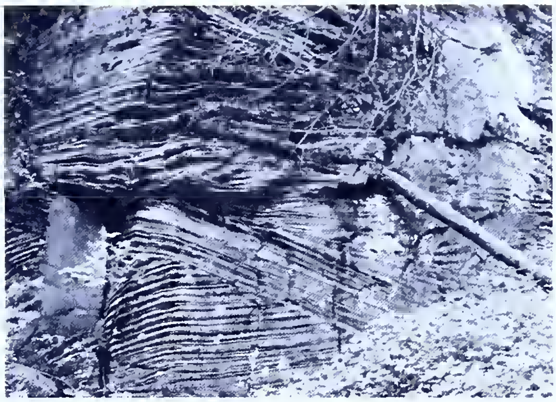


Figure 1. Crossbedding in the Loyalhanna Limestone in the Blue Stone quarry at Linn Run State Park, Westmoreland County. Crossbedding can be seen at other state parks such as Baughmans Rocks overlook, Ohiopyle State Park, Fayette County; the Forest Fire Warden Monument, Hyner View State Park, Clinton County; Phyllis Run at Clear Creek State Park, Beartown Rocks area, Jefferson County; Geology Trail, Oil Creek State Park, Venango County; and The Glens, Ricketts Glen State Park, Luzerne County.

The cross-cutting patterns could have been created by changes in water current direction, as shown in Figure 2.

One could have easily used a wind-blown desert setting and had similar features created by wind instead of water currents, or a beach setting where a combination of wave action and wind could produce similar crossing patterns.

Figure 1 shows a sedimentary rock feature called crossbedding. It is characterized by a distinctive cross-cutting pattern. Thin layers within a bed (laminae) or thin beds appear to cross-cut other sets of layering. The thin layers are typically parallel to one another and are inclined at some angle.

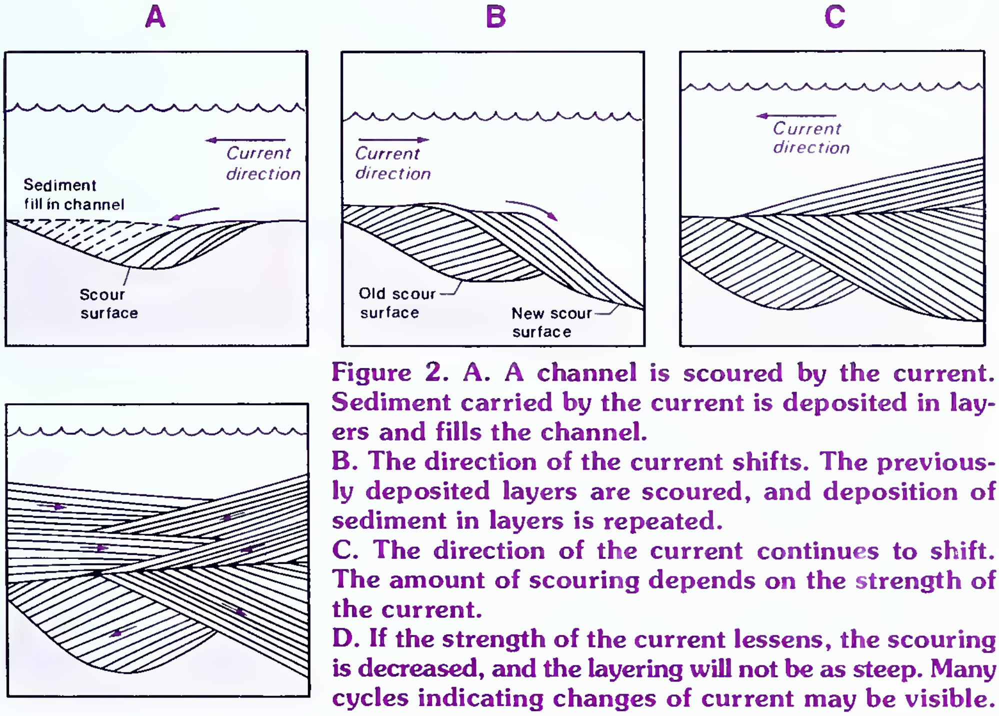
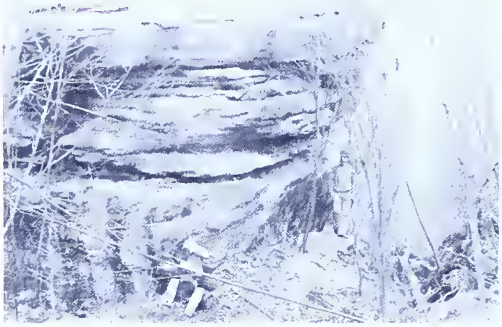


Figure 2. A. A channel is scoured by the current. Sediment carried by the current is deposited in layers and fills the channel.
B. The direction of the current shifts. The previously deposited layers are scoured, and deposition of sediment in layers is repeated.
C. The direction of the current continues to shift. The amount of scouring depends on the strength of the current.
D. If the strength of the current lessens, the scouring is decreased, and the layering will not be as steep. Many cycles indicating changes of current may be visible.

As one examines the rocks more closely, the clues become more obvious. Let us continue to explore this idea of different environments.

MYSTERY 2. Travel north with us to Warren County and stand among huge, house-sized boulder (Figure 3). What do these rocks tell us?

It is easy to see that the rock is composed of pebbles of different sizes and that the pebbles are rounded. Imagine places where pebbles of this size and shape can be found. One of the most common places is in streams, particularly streams that have fast-moving water. The pebbles are made smaller and rounder by abrasion as they are bounced along the bed of the stream by the fast-moving water.



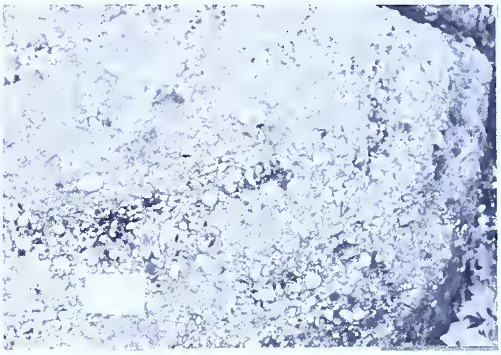


Figure 3. Huge conglomerate boulders make interesting "rock cities" atop the ridges of plateau country, Chapman State Park, Warren County. Boulder cities can be seen at other state parks such as Clear Creek State Park, Beartown Rocks area, Jefferson County; along Geology Trail, Oil Creek State Park, Venango County; and at the Rock Garden in Worlds End State Park, Sullivan County.

The pebbles found in the conglomerate compare to pebbles found in existing streams. We can use the relationship between present and past environments to help us interpret the features found in different rocks. In this instance, the pebbles in the conglomerate were deposited by a fast-flowing stream during the Pennsylvanian Period, about 310 million years ago.

The rocks described in the mysteries are sedimentary rocks, the most common type of rock seen in Pennsylvania's state parks. Conglomerate, sandstone, siltstone, shale, and limestone are all sedimentary rocks.

MYSTERY 3. Beds of sedimentary rocks are generally in horizontal layers. At Whipple Dam State Park, Huntingdon County, the beds of sandstone appear to be folded (Figure 4). How did these rock layers get folded?

Observe in Figure 5 how an applied force (your hand pushing from one end of a rug) acts on an attached, relatively stationary ob-

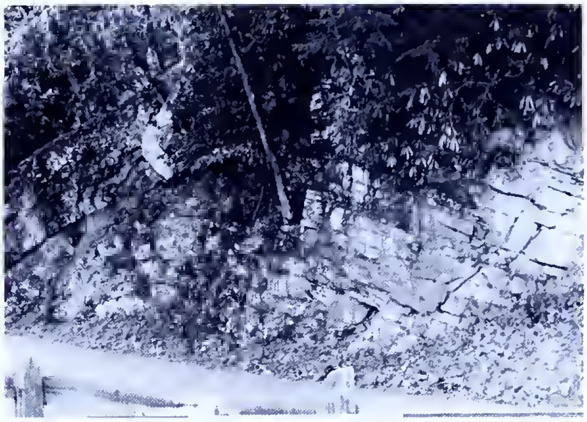


Figure 4. Gently folded bedrock along Whipple Road near the dam, Whipple Dam State Park, Huntingdon County.

ject (the piece of rug). Pushing from one direction compresses the rug and shortens it, causing the fold. When the continental plates that make up the earth's crust came together during the Alleghanian orogeny, the compressional force from the collision was passed on to the different layers of rock, shortening the layers and causing them to be folded.

Inclined bedding prevails in the Ridge and Valley province. The photograph on the cover shows a section of rock layers in Warriors Path State Park that were originally horizontal and have been folded. The exposed section is just one part of a larger fold. If the vegetation were removed, additional rock layers would be visible, and they would reflect the same inclination. This inclination of bedding is called the dip of a bed (Figure 6). Dip is measured in degrees from a horizontal plane. The dip of a bed helps to identify the orientation of the rock layers in a given area.

The outcrop shown on the cover is part of the west side of a large syncline that includes the Broad Top coal field. Anticlines and synclines are specific types of folds that occur throughout much of Pennsylvania. If the letter "S" is laid on its side, it looks much like a syn-

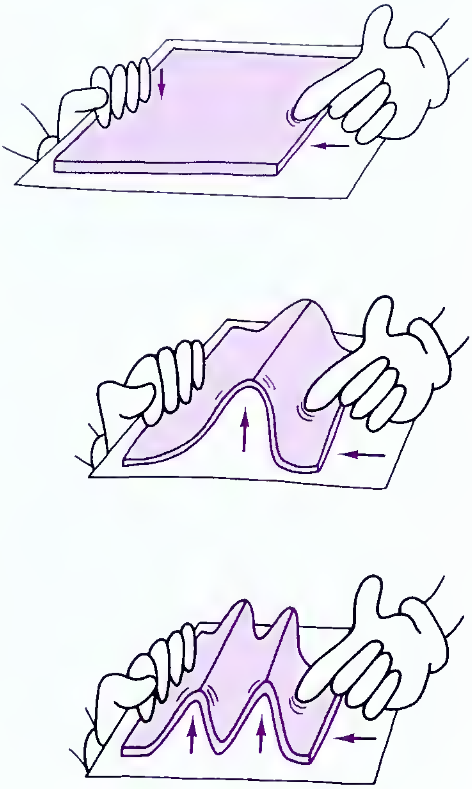


Figure 5. To get a general idea of how rock layers are folded, take a piece of rug, and hold down one end while slowly pushing from the other end. You will note that the piece of rug will bulge at or near the center. Continue to push the rug and it may develop more than one fold, giving the surface a rippled appearance.

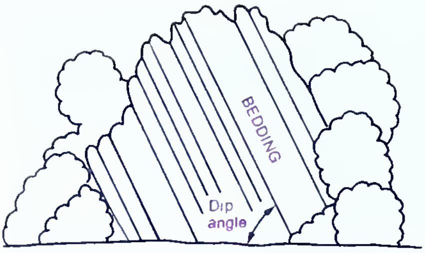


Figure 6. Inclined bedding showing dip angle.

cline and anticline sequence (Figure 7). However, there is more to understand about anticlines and synclines than their shape. Because of the way the rocks are folded, an anticline has the oldest layers of rocks in the core of the fold, whereas a syncline has the youngest rocks in the core. Notice how the dip of the beds changes from left to right in Figure 7.

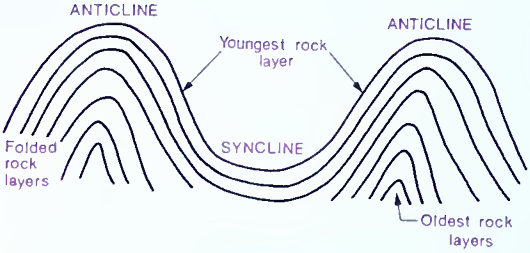


Figure 7. Anticline and syncline.

At Warriors Path, the layers of rock are composed of sandstone and siltstone, which are more resistant to erosion. More easily erodible shale, to the right of the outcrop, is therefore not as prominent as the sandstone and siltstone layers.

MYSTERIES SOLVED? We have been to different parts of Pennsylvania, visited some of the state parks, and examined some of the rocks found there. We have noted that the rocks contain clues to help unravel part of their mystery. The mystery is only solved in part because we are only looking at one clue in a much larger picture.

The Pennsylvania Geological Survey is in the process of preparing a book about the geological story of our state parks for publication in a format similar to this article (Kochanov and others, in press). We will share with the visitor and the armchair traveler some of the geologic features to be seen in our state parks and the clues found within the rocks that help explain some of the mysteries of how the rocks were formed.

The author thanks W. D. Sevon, Pennsylvania Geological Survey, for his help in the early stages of manuscript preparation, and J. H. Barnes and D. M Hoskins, Pennsylvania Geological Survey, who reviewed the article and made several helpful suggestions.

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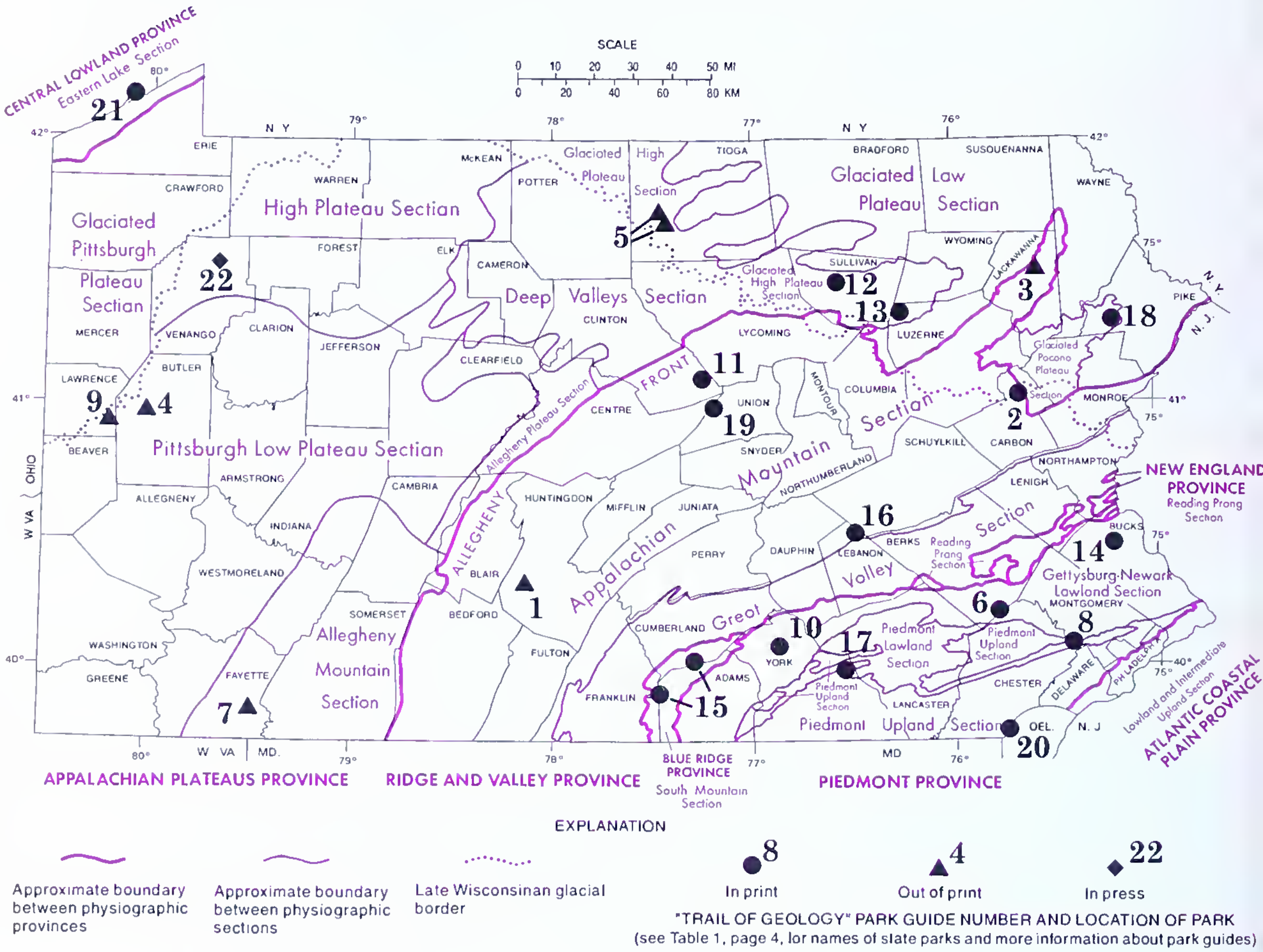

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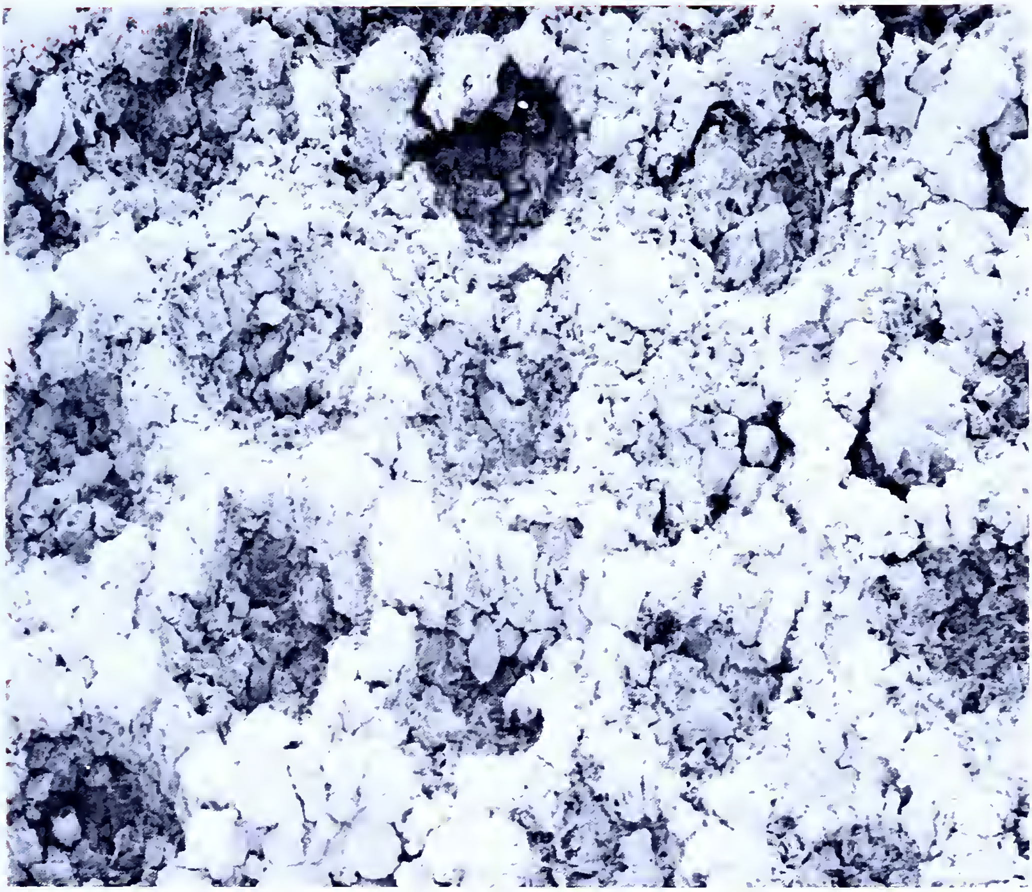

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CONTENTS

We're on the web! 1
Fossil "rolling stones": bryozoan nodules in the Keyser Limestone (latest Silurian) at the Mexico railroad cut, central Pennsylvania 2
An unusual occurrence of ooids in the Speechley sand of western Pennsylvania 8
New releases 13

ON THE COVER

Scanning-electron photograph of a bryozoan nodule exterior surface, greatly magnified (x130), showing zooecial openings of the predominant species *Diplotrypa franklini*; from the lower part of the Keyser Limestone (latest Silurian) at the Mexico railroad cut in central Pennsylvania (see article on page 2).

PENNSYLVANIA GEOLOGY

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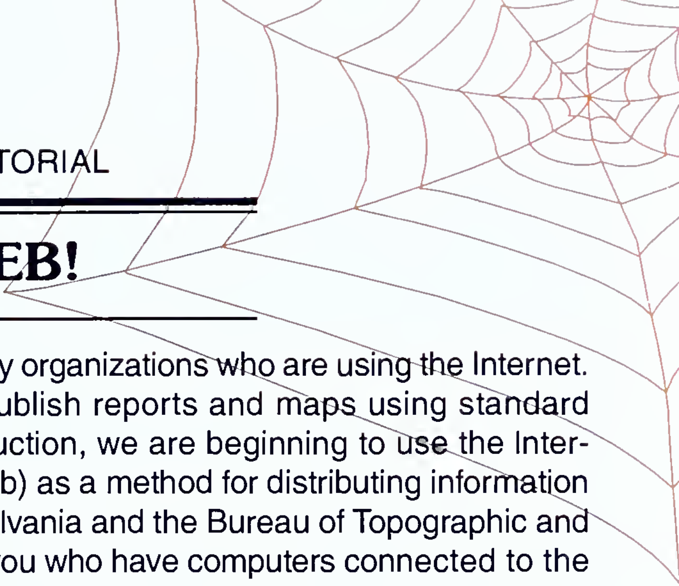
STATE GEOLOGIST'S EDITORIAL



We're on the WEB!

We have joined the many organizations who are using the Internet. While we will continue to publish reports and maps using standard printing and graphic reproduction, we are beginning to use the Internet's WWW (World Wide Web) as a method for distributing information about the geology of Pennsylvania and the Bureau of Topographic and Geologic Survey. Those of you who have computers connected to the Internet may examine our home page and additional pages by typing the Universal Resource Locator (URL) http://www. dcnr.state.pa.us/dcnr/deputate/topogeo/default.htm. Make sure you have all of the periods and forward slashes in their correct place or it won't work.

We plan to make our WWW pages informative, interactive, and visually pleasing. To do this, we will need your comments, evaluations, and recommendations for the types of information that you wish to receive using this new technology. So tell us what you would like to see in these pages, and we will strive to meet your needs.

If you search our present pages, you will be able to search on a number of maps showing the locations of the many libraries throughout Pennsylvania, the United States, and in foreign countries where our publications are reposited. These maps were created for us by a geology student intern, Mike Cypcar, from Indiana University of Pennsylvania.

Present plans include remodeling of our "front page" and creating an interactive physiographic provinces map of Pennsylvania (the physiographic provinces map was recently revised and is also being printed in full color at page size). The Internet version will include connections to pages which portray scenes and text descriptions of places to visit that clearly demonstrate the nature of the physiography (landform) of each province and section. To each of these pages we plan to add individual descriptions of specific localities where geologic features may be examined, as well as sites to visit for fossil and mineral collecting.

If you have any comments you wish to send to me via e-mail, my address is hoskins.donald@a1.dcnr.state.pa.us.

See you on the WWW!

Donald M. Hoskins

Donald M. Hoskins
State Geologist

FOSSIL "ROLLING STONES":
Bryozoan Nodules in the Keyser Limestone (Latest Silurian) at the Mexico Railroad Cut, Central Pennsylvania

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INTRODUCTION. "Rolling stones" conjure up musical connotations for most people, but fossil "rolling stones" also exist (though silently) and represent a highly unusual kind of geological occurrence, one that has now been found in central Pennsylvania.

These unusual fossils are actually nodules built by species of Bryozoa, one of the major animal phyla. These rounded, unattached masses were rolled around on shallow sea bottoms by waves or currents, and are sometimes termed "bryoliths" or "ectoproctaliths." Each nodule consists of concentric bryozoan encrustations, much like a tiny reef structure, except that the nodules were passively mobile instead of firmly fixed in one place. Because of this type of internal construction, such bryozoan nodules can be best understood by comparing them with bryozoan reefs and reef-rock (Cuffey, 1977, 1985).

Thus far, few nodule occurrences have been analyzed, and so the discovery of numerous bryozoan nodules or "lumps" in the Keyser Limestone (uppermost Silurian) at the Mexico railroad cut in Juniata County, central Pennsylvania, is of great paleontologic interest. Moreover, because these fossils are so similar to certain living counterparts, their study makes it possible for us to envision ancient central Pennsylvania quite vividly.

LOCATION AND HORIZON. The bryozoan nodules are found in the northwest corner of the large railroad cut at 40°31′55″N/77°21′09″W, Mexico 7.5-minute quadrangle, Juniata County. The locality is 1.6 mile (2.9 km) along the Conrail mainline tracks, southeast from the bridge

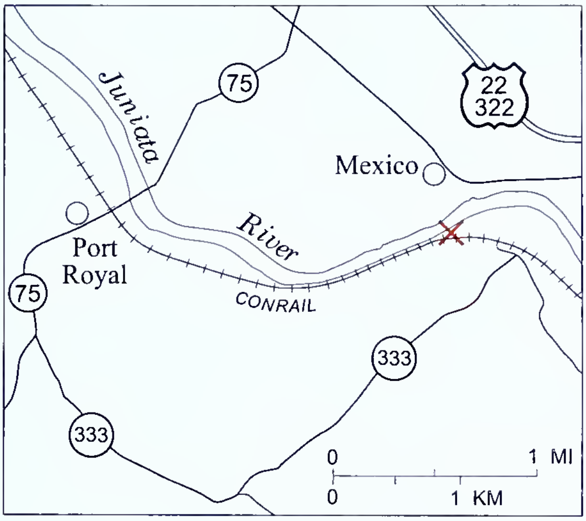

Figure 1. Location (X) of bryozoan nodules in the Mexico railroad cut southeast of Port Royal, Juniata County. Base map from U.S. Geological Survey Mexico and Mifflintown 7.5-minute quadrangles.

in Port Royal that carries Pa. Route 75 over the railway, and is directly south across the Juniata River from the small village of Mexico (Figure 1). Note that this is a major rail line—CAREFUL ATTENTION TO SAFETY is necessary when visiting this locality! Permission to visit the site should be obtained from Conrail.

The nodules occur in the lower part (Byers Island Member) of the Keyser Limestone (Figure 2), which here is latest Silurian in age, about 400 million

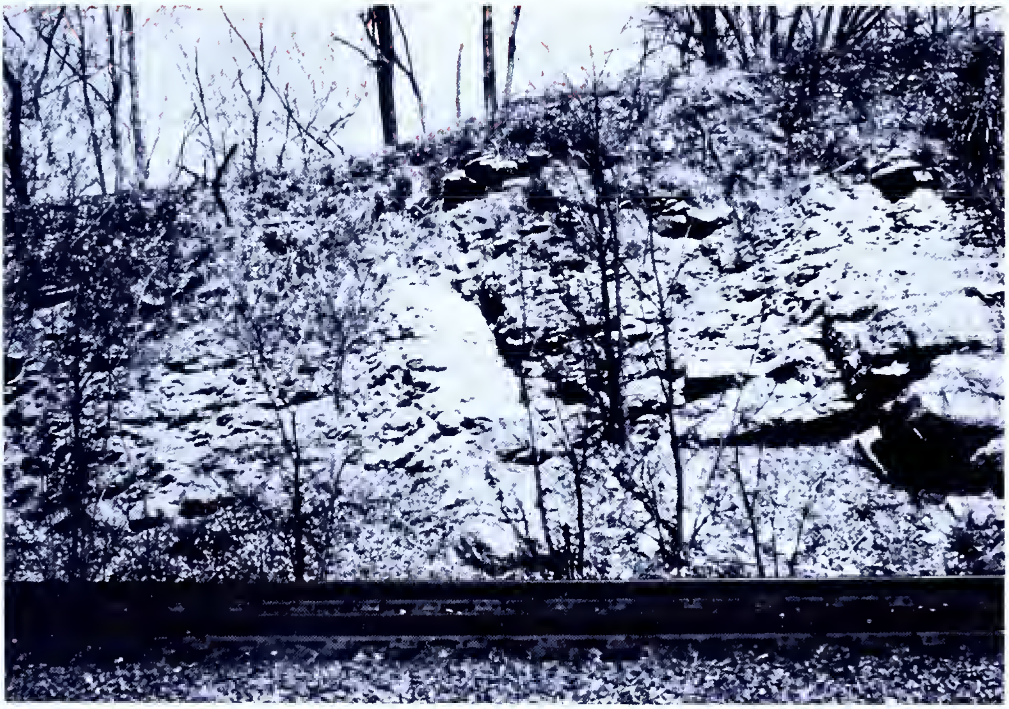

Figure 2. Northwest face of the Mexico railroad cut, showing the lower part of the Keyser Limestone. The in-place bryozoan nodules are scattered through the middle strata exposed here. Nodules can also be found weathered free along the foot of the cliff.

years old. The nodules are embedded in gray-weathering, thin- to nodular-bedded, micritic to calcarenitic to bioclastic limestones, separated by calcareous shale laminae. Branching, bifoliate, and encrusting bryozoans, along with strophomenid and atrypid brachiopods, are the predominant fossils at this outcrop, although rarely other groups are also seen.

NODULE CHARACTERISTICS. Superficially, the bryozoan nodules look like rounded stones (Figure 3A). However, close examination shows that the exterior surface is covered all the way around with pinprick-sized zooecial openings (see cover photograph). This results from the nodule having been overturned periodically by waves or currents. The surviving zooids grew around onto the newly exposed surfaces of the mass during the quiet intervals between overturnings.

The nodules vary from elongated, flattened, or ovoid to almost spherical; some have distinct lobes along their margins. Each nodule consists of from three to seven concentric layers (Figure 3B); each layer and lobe exhibits finely radial structure due to the upwardly and outwardly radiating zooecial tubes. Many nodules show distinct white and brown layers, the result of preservation by calcite and silica, respectively.

SPECIES COMPOSITION. The bryozoan nodules contain nine different species (Table 1), of which only one is dominant; their descriptions are detailed in Bolton (1966), Ulrich and Bassler (1913),

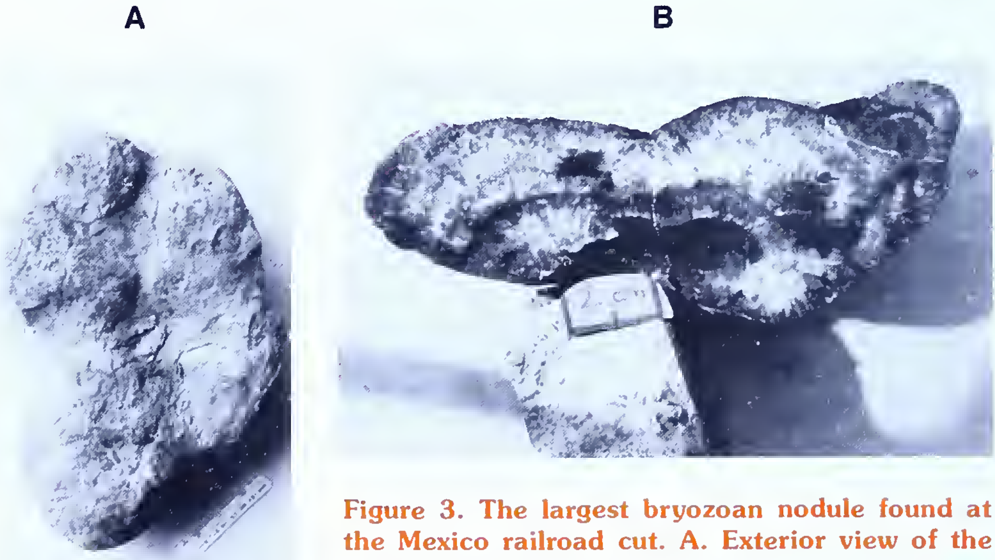

Figure 3. The largest bryozoan nodule found at the Mexico railroad cut. A. Exterior view of the flattened side. B. Polished cross section through the longest dimension (13 cm).

Table 1. *Bryozoan Species in Nodules, Mexico Railroad Cut*
(**Abundant; *common; all others rare)

- TREPOSTOMIDA
  - Monotrypidae
    - *Cyphotrypa corrugata* (Weller)
    - *Cyphotrypa expanda* Bassler
  - Diplotrypidae
    - ***Diplotrypa franklini* Bolton
  - Trematoporidae
    - *Stromatotrypa globularis* Ulrich and Bassler
  - Halloporidae
    - *Leioclema pulchella* Ulrich and Bassler
- TREPOSTOMIDA *(cont.)*
  - Halloporidae *(cont.)*
    - *Leioclema subramosa* Ulrich and Bassler
    - *Leioclema tenuirama* Bassler
- CERAMOPORINA
  - Ceramoporidae
    - *Ceramopora incondita* Ulrich and Bassler
- FISTULIPORINA
  - Fistuliporidae
    - **Fistuliporella constricta* (Hall)

and Bassler (1923). Some nodules consist entirely of one species, others two, and some three (not always the same three).

Abundant and nearly ubiquitous in the nodules are crustose, massive, and hemispherical colonies of the trepostome *Diplotrypa franklini* (Figure 4A and 4B), characterized by subcircular, large (0.5 to 0.6 mm in diameter), thin-walled zooecia (the tubes secreted around the polyps), containing few diaphragms (cross-partitions) and separated by small mesopores (spaces between the polyp tubes), which are angular in tangential section to bubblelike in longitudinal section.

NODULE PALEOECOLOGY. Recent regional studies (Smosna, 1988) indicate that the Keyser Limestone was deposited around the margins of a shallow bay, in a complex of semi-enclosed lagoons, interconnecting channels, mud flats, and sandy shoals along the ancient coast. The nodular-bedded micritic limestone of the lower Keyser, just above the flat-bedded Tonoloway Formation, suggests deposition in an ancient coastal lagoon (Brezinski and Kertis, 1982).

Dominance by bryozoans and calcareous brachiopods further implies essentially marine waters, but the scarcity of other phyla (especially echinoderms) may indicate slightly reduced salinity compared with the open sea, or extreme seasonal variations in salinity, as would be expected in coastal waters diluted by rainfall and runoff. The same salinities are also suggested by the fact that only one of the several bryozoan species, *Diplotrypa franklini*, is abundant or dominant in the nodules.

The similarity of the paleoenvironment of the Keyser bryozoan nodules to modern counterparts along the Delmarva coast (Dade and Cuffey, 1984) permits visualizing Pennsylvania during Silurian-Devonian time much more vividly than is ordinarily possible in geo-

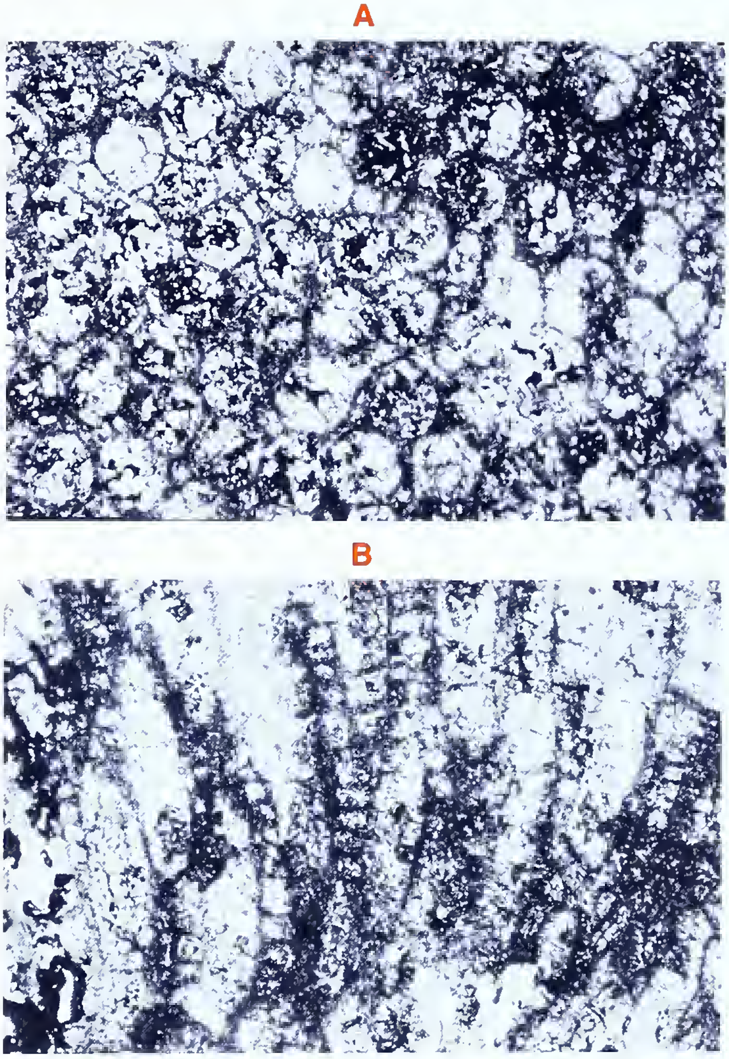

Figure 4. Tangential (A) and longitudinal (B) peel sections (both x18) of the important or dominant nodule bryozoan species, *Diplotrypa franklini.* Specimens are in the Paleobryozoological Research Collection at The Pennsylvania State University, State College.

logic studies. Thus, Figure 5 shows a nodule-forming coastal lagoon, flanked landward by tidal flats and seaward by barrier islands, visible in the distance. During the mid-Paleozoic, this is the sort of view that someone standing at Port Royal or the Mexico railroad cut would have had if facing southwestward, toward Altoona, out across the open shallow sea beyond the barrier islands.

CONSTRUCTIONAL IMPLICATIONS. The bryozoan nodules at the locality examined confirm the broad constructional capabilities of bryozoan colonies and demonstrate that those capacities extend well back into geologic time. The bryozoans here were the principal frame-builders of the nodules; they formed a series of concentrically nested, shell-like crusts, the kind of limestone reef-rock known as a cruststone (Cuffey, 1977, 1985).

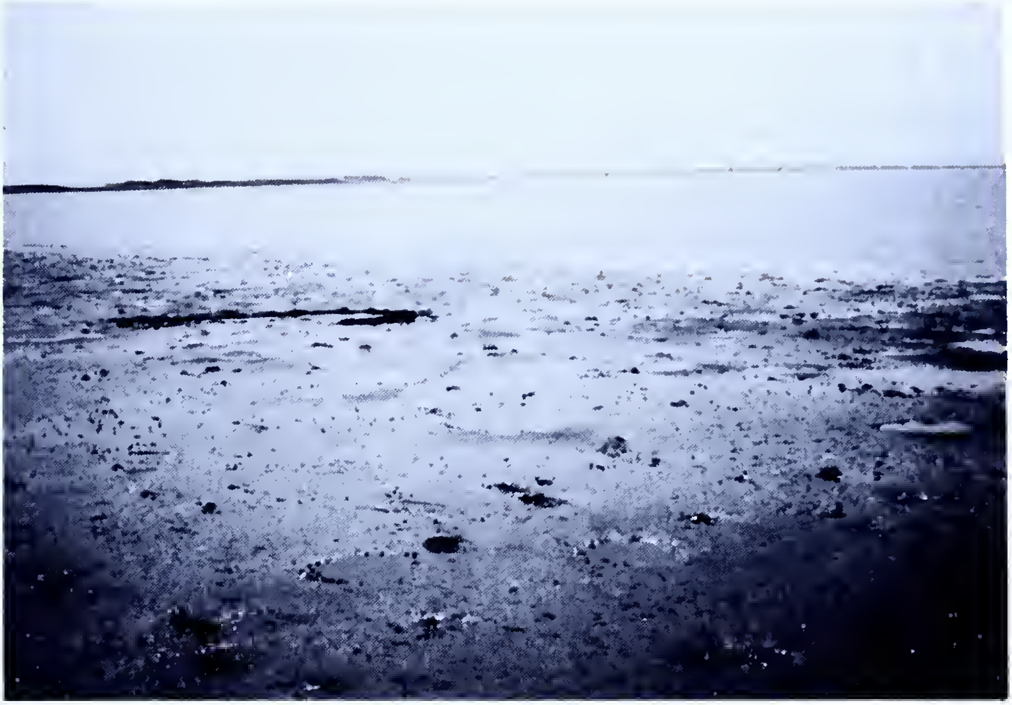

Figure 5. During latest Silurian time, the area of the Mexico railroad cut in central Pennsylvania might have looked like this present-day coastal lagoon containing bryozoan nodules, along the Atlantic coast of the Delmarva Peninsula.

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An Unusual Occurrence of Ooids in the Speechley Sand of Western Pennsylvania

by Christopher D. Laughrey and Robert M. Harper*
Pennsylvania Geological Survey

INTRODUCTION. While doing routine microscopic examinations of rock samples as part of a reconnaissance study of Pennsylvania's petroleum reservoir rocks, we found an unusual occurrence of calcite ooids in the Speechley sand of the Bradford Group. Ooids are spherical or subspherical, sand-sized carbonate particles consisting of concentric lamellae around a nucleus, often a fossil fragment or a sand grain. When ooids are found in rocks, they are a valuable constituent because they form in a narrow range of environments and are thus useful for interpreting the depositional setting in which they originated. The Bradford Group is Late Devonian in age and comprises an entirely subsurface sequence of lenticular sandstones and siltstones interbedded with marine shales. Speechley sand is an informal name used by drillers for one of the more widespread sandstone and siltstone gas reservoirs within the Bradford Group.

In central-western Pennsylvania, the Speechley typically is a light-gray, well-consolidated sandstone interbedded with dark-gray shales (Glohi, 1984). The sandstones display low-angle to parallel laminations, cross-stratification, ripples, and trace fossils. Erosional basal contacts and related sole marks are common, as are shale intraclasts and coquina hash (Glohi, 1984; Greenawalt, 1984).

We found the ooids in samples of the Speechley sand taken from a core recovered from the Wilda M. Stewart gas well in Cowanshannock Township, Armstrong County. Twenty-nine feet of the Speechley sand interval was retrieved from this well (Figure 1). Ooids occur within a 2.25-foot interval of the core, between 2,865.75 and 2,868 feet. This interval consists of medium- to light-gray, bioturbated and wave-ripple-laminated sandstone.

THE SPEECHLEY OOIDS. Ooids make up 10 percent of the bulk mineralogy of the sandstones. Ooid grain sizes range from 0.15 to 0.4 mm in diameter. The outer coat of the ooids consists of concentrically lamellar microcrystalline calcite (Figure 2). Within this coat, the nucleus is mostly detrital quartz, but feldspar and rock fragments

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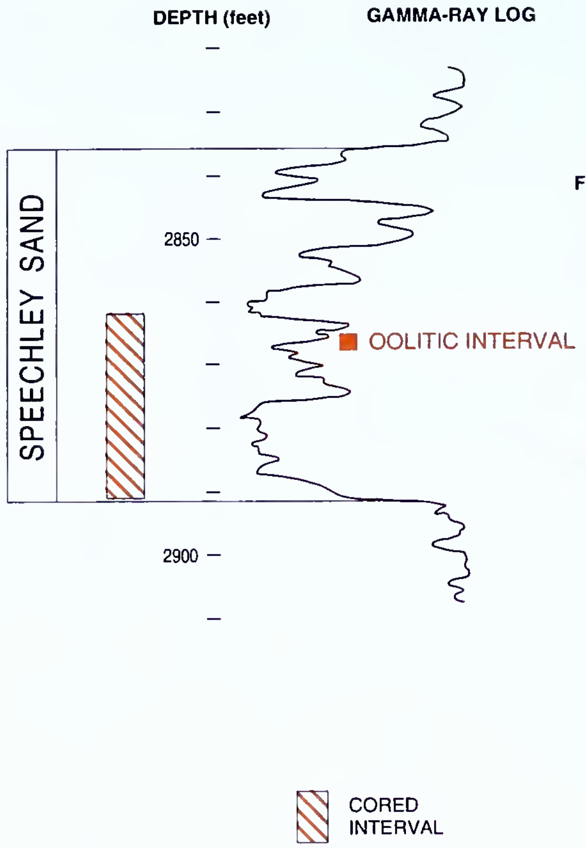
*Deceased.



FACIES	INTERNAL STRUCTURES AND FEATURES	PROCESS INTERPRETATION	ENVIRONMENTAL INTERPRETATION
Hb	Bioturbation, graded sandstone lenses, scour surfaces, low-angle and paralell laminations, weve-ripple cross-lamination, ooids	Graded lenses deposited from suspension; variable cross-laminations and wave ripples represent upper-flow-regime coniditions followed by wave reworking; bioturbation during fair weather	Distal storm deposits or less intense energy conditions associeted with lesser storms
Ha	Low-angle and trough cross-laminations, parallel to cross-laminations	Combination of bedload and suspension deposition of sand; currents of decreasing strength	Combination of high-energy conditions associated with wave action and storm-generated currents
Ma	Graded, bioturbated sandstones and laminated mudrock	Deposition from suspension	Low-energy, basin-margin surface

SHALLOW-MARINE SILICICLASTIC FACIES TYPES

Hb	Heterolithic facies; mixed sandstone and mudrock
Ha	Heterolithic facies; sandstone-dominated
Ma	Mud facies; graded sandstone layers in marine mudrock

Figure 1. Gamma-ray log of the Speechley sand interval in the Stewart well showing the core interval, the oolitic interval, and an interpretation of the depositional environment in which the rocks formed.

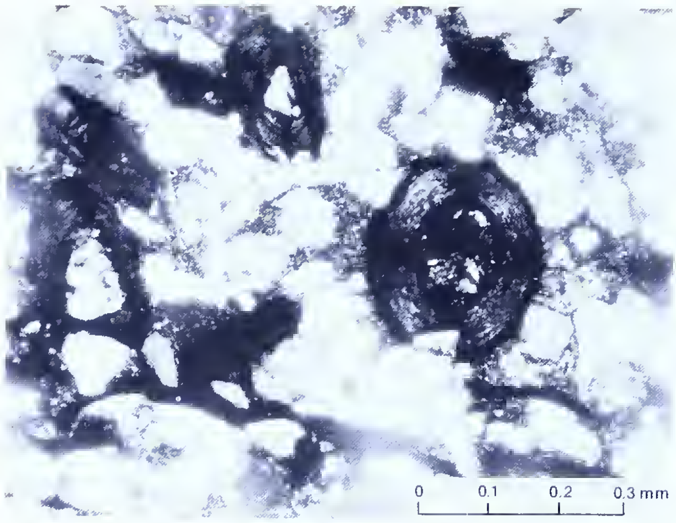


Figure 2. Ooids in the Speechley sand.

such as chert, shale, dolostone, metamorphic and volcanic chips, and even accessory sand grains like zircon also serve as nuclei. A few ooids appear to have nuclei comprised of crystalline calcite or single dolomite rhombs, but we suspect that these are replacement minerals. The ooids contain organic matter, located mainly between lamellae and in microcrystalline layers. Most of the ooids have micrite envelopes and encrustations, that is, rinds of cryptocrystalline calcite which formed through postdepositional diagenetic alteration of the original calcite grains. About 95 percent of the ooids are elongate and elliptical in shape. They show evidence of strong deformation; many exhibit concentric laminae sheared from the nucleus. In some instances, strong compression has sheared off the cortex of the nuclei and produced calcite grains that no longer resemble ooids. Carbonate cementation in the sandstones appears to postdate deformation. Many ooids are in pressure-solution contact with other constituents of the sandstones.

Most modern ooids form in marine environments within or near the intertidal zone where waves break and pound. In such an environment, ooids might form inorganically as cooler water from adjacent deeper areas spreads across shoals and warms; carbon dioxide is presumably removed from dissolved calcium bicarbonate, and a rim of calcium carbonate is precipitated as a coating on available nuclei. Some investigators suspect that this mechanism is too simple and suggest that blue-green algae may be involved in the precipitation of ooids (Friedman and Sanders, 1978). Although less common, ooids also form in the quiet waters of lagoons, lakes, and rivers, and on tidal flats in fresh and hypersaline waters. Laboratory synthesis of ooids has suggested that organic compounds are instrumental in the formation of quiet-water ooids, but that ooids formed in turbulent, agitated waters are precipitated inorganically (Davies and others, 1978). In all cases, ooids have a relatively simple transport history, usually growing at or near their site of deposition (Heller and others, 1980).

SIGNIFICANCE OF THE OOIDS IN THE SPEECHLEY SAND. Two types of depositional environments have been suggested for the Speechley sand in central-western Pennsylvania. Greenawalt (1984) proposed that the Speechley sand in the Cherry Hill gas field of Indiana County was deposited as a turbidite channel fill. He based his interpretation on sand-body geometry and the presence of a downcutting erosional contact with underlying marine shales. Greenawalt reinforced this interpretation with core descriptions in which he documented incomplete Bouma sequences and fining-upward grain size trends. Glohi (1984), on the other hand, interpreted the Speechley sand in the Indiana gas field of Indiana County as a nearshore marine deposit. He suggested deposition of offshore sandbars in a delta-margin environment. Glohi (1984) cited the presence of fossils and biogenic structures, glauconite, minor conglomerate accumulations, and gamma-ray-log signatures as evidence for his interpretation.

The ooids in the Speechley sand in the cores from the Stewart well present an opportunity to appraise the two proposed depositional models. Our interpretation of the entire cored Speechley interval from the Stewart well is summarized in Figure 1. The basal 3 feet of core consists of graded and bioturbated, micaceous sandstone interbedded with mudrock. This sequence is overlain by 13 feet of medium- to very fine grained sandstone. This interval exhibits low-angle and trough cross-laminations and parallel laminations. The upper 7 feet of core, which contains the ooids, consists of very fine grained sandstones interbedded with mudrocks. The sandstones exhibit grading, low-angle and parallel laminations, wave-ripple cross-laminae, scour surfaces, and bioturbation. The mudrocks are also bioturbated.

We interpreted the core sequence according to the facies scheme of Johnson (1978) for shallow siliciclastic seas. This scheme is based on the recognition of "heterolithic" associations, which consist of interbedded sandstone and mudrock with proportions that vary from sand dominated (75 to 90 percent sandstone) to mixed (50 to 75 percent sandstone) to mud dominated (10 to 50 percent sandstone) (Johnson, 1978, p. 233). The assignment of these proportions to different parts of the Speechley core is shown in Figure 1.

We reject the classical turbidite model for the Speechley sand in the Stewart well because of the presence of well-developed oscillatory wave-ripple lamination and the evidence for extensive reworking of the sediments by organisms. Density currents did traverse the shallow seafloor during storms, as evidenced by the graded sequences and their associated scour features, but the fact that they were reworked by wave currents places them in shallow water, at least above storm wave base. The ooids are restricted to one small interval within the mixed sandstone and mudrock facies. If the Speechley were deposited as a turbidite channel fill and the ooids were transported over some distance from a more proximal shoal area, we would expect to find them dispersed throughout the Speechley interval. This is not the case. The ooids only occur within a wave-rippled and bioturbated zone, or, in other words, in a shallow-water environment that was agitated by wave action and that supported a benthic marine infauna.

A modern analogue for the environment in which we feel the Speechley sand formed is the Carolina continental shelf off the southeastern United States. Cleary and Thayer (1973) described the petrography of carbonate sands that are mixed with the dominant terrigenous sediments in this area. The percentage of carbonate grains on the shelf is a function of dilution by siliceous clastic sediments. The latter consist of quartz, feldspar, rock fragments, heavy minerals, and glauconite. Regional variations in Carolina shelf sand mineralogy are very similar to the variations in the mineralogy of the Bradford Group sandstones described by Glohi (1980). In Figure 3, we compare the mineralogy of the oolitic Speechley sand interval with some of the data from the modern Carolina shelf. On the Carolina shelf, ooids average 6 percent of the sand fraction and form a maximum of 15 percent. The ooids formed between 24,600 and 27,650 years ago in a shallow, hypersaline environment that existed behind calcareous shoals (Cleary and Thayer, 1973). The ooids have since mixed with the now predominant terrigenous clastics through normal shelf processes during Holocene sea-level rise. They are most concentrated

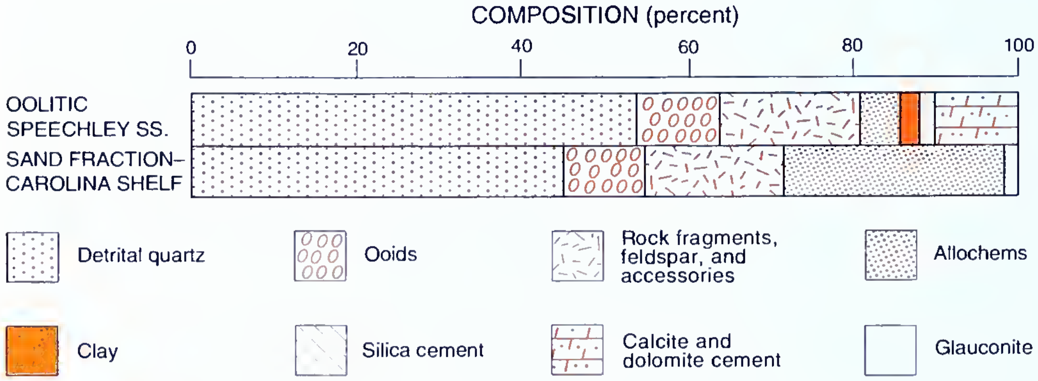


Figure 3. A comparison of the mineral compositions of the oolitic Speechley sand and the sandy sediments of the Carolina shelf that contain ooids.

near the position of the original ooid shoals and become less common in the shelf sediments away from their site of origin.

Future petrographic work may document more occurrences of ooids in the sandstones of the Bradford Group in western Pennsylvania. Such findings could improve our understanding of the kinds of sedimentary processes that acted on the ancient floor of the Devonian sea.

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NEW RELEASES

Groundwater Resources of Delaware County

The Pennsylvania Geological Survey recently published Water Resource Report 66, **Groundwater Resources of Delaware County, Pennsylvania.** Authored by Wayne T. Balmer and Drew K. Davis of the U.S. Geological Survey, the report consists of a 67-page text accompanied by a full-color 1:50,000-scale geologic map showing the locations of selected wells.

The text contains a summary of the geologic and hydrologic characteristics of the six major water-bearing formations in the county, including water quality; a brief discusion of the factors that influence groundwater flow; a summary of the nature of and service areas for the large public water suppliers in the county; construction, production, and ownership data for nearly 400 wells; laboratory results of organic and inorganic analyses of water samples; and discharge data from five stream basins in the county, which is useful for estimating available water resources.

Water Resource Report 66 may be purchased from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17105–1365, for **$11.50 plus $0.69 state sales tax** for Pennsylvania residents. Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Those who previously purchased only the plate for this report may now purchase the accompanying text for $2.55. This price includes shipping, handling, and state sales tax. If ordering only the text, please send a check, payable to *Commonwealth of Pennsylvania*, to Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

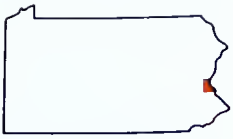
Coal Resources of Indiana County

The Pennsylvania Geological Survey has released **Mineral Resource Report 98, Coal Resources of Indiana County, Pennsylvania—Part 1, Coal Crop Lines, Mined-Out Areas, and Structure Contours**. The report, by W. A. Bragonier of the Rochester and Pittsburgh Coal Company and Albert D. Glover of the Pennsylvania Geological Survey, contains a short introductory text and 122 two-color quadrangle-based maps printed at a scale of approximately 1:62,500 in an 8½-by 11-inch loose-leaf format. For each of the twenty-six 7.5-minute topographic quadrangles that cover Indiana County, there is a separate map for each minable coal seam showing the coal outcrop lines and the extent of all known strip and deep mining. An additional composite map for each quadrangle contains the outcrop lines of all principal coal seams, as well as structure contours defining broad regional folds in the rocks.

The report provides valuable coal-resource information for future exploration and mining programs that support local employment and the local area economy. Additionally, the report provides framework information for environmental and land use planning. The structure contours drawn on several of the coal seams portray the fold structures in the county and thus provide reference information for geologic studies in other stratigraphic units.

Mineral Resource Report 98 may be purchased from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17105–1365, for **$15.80 plus $0.95 state sales tax for Pennsylvania residents.** Orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

Surficial Geology of the Easton, Riegelsville, and Frenchtown Quadrangles



The Pennsylvania Geological Survey has recently released three new open-file reports in the second installment of a series of 28 surficial geologic maps of 7.5-minute quadrangles in the Allentown 30- by 60-minute map sheet. The reports are **Open-File Report 96–38, Surficial Geology of the Pennsylvania Part of the Easton 7.5' Quadrangle, Northampton County, Pennsylvania**; **Open-File Report 96–45, Surficial Geology of the Pennsylvania Part of the Riegelsville 7.5' Quadrangle, Northampton and Bucks Counties, Pennsylvania**; and **Open-File Report 96–46, Surficial Geology of the Pennsylvania Part of the Frenchtown 7.5' Quadrangle, Bucks County, Pennsylvania**. All three reports are by Duane D. Braun of Bloomsburg University.

Each report consists of a one-color (black) photocopy of a 1:24,000-scale geologic map with a skeletal legend of from 12 to 32 surficial map units and a 5- to 12-page text, which includes detailed descriptions of the map units, a short discussion of mapping methodology and glacial history, a table showing the relationship between mapping units and county soil series, and a sketch map of glacial borders in the Allentown 30- by 60-minute map sheet. The latter is not included in the Frenchtown report, because that quadrangle contains no glacial deposits.

The cost of each report is **$2.50 plus $0.15 state sales tax** for Pennsylvania residents. Please see the following announcement for instructions on ordering.

Surficial Geology of Warren County

A new open-file report on the surficial geology of Warren County, northwestern Pennsylvania, has been released by the Pennsylvania Geological Survey. The report, by staff geologist W. D. Sevon, is a companion to previously released Open-File Report 95–02 (*Bedrock Geologic Map of Warren County, Pennsylvania*; see *Pennsylvania Geology*, v. 26, no. 3/4, p. 8), and includes a one-color (black) 1:50,000-scale reconnaissance geologic map of the surficial deposits of the county showing the late Wisconsinan and pre-Illinoian glacial boundaries, and a 10-page text containing a discussion of the texture, thickness, and origin of the mapped units.

Open-File Report 95–03, **Surficial Geology and Geomorphology of Warren County, Pennsylvania,** may be purchased from the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, for the prepaid copying and shipping costs of **$3.00 plus $0.18 state sales tax** for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*. The report may be examined in the library of the Pennsylvania Geological Survey, Evangelical Press Building, Second Floor, 1500 North Third Street, Harrisburg, and in the Pittsburgh office of the Survey at 500 Waterfront Drive.

For further information on open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–787–6029.

Mineral Products Directory Completed

A new directory of nonfuel-mineral producers in Pennsylvania is available. The directory provides detailed information about the location and products of 695 nonfuel-mineral-producing sites in Pennsylvania. To be published as Information Circular 54, *Directory of the Nonfuel-Mineral Producers in Pennsylvania*, 5th ed., the new directory replaces the 1985 printed edition, which proved very useful but is now 10 years out of date. Information from this directory is now available by writing to the Bureau at P. O. Box 8453, Harrisburg, PA 17105–8453, or by e-mail to barnes.john@a1.dcnr.state.pa.us.

The directory format is similar to earlier editions. Mineral producers are assigned a number that identifies them on a large-scale state map that will accompany the printed report. To improve the new directory, latitudes and longitudes of mineral-producing sites and the name of the topographic quadrangle on which each operation is located are included.

The new directory was compiled following advice from a Bureau ad hoc advisory committee, the Geologic Resources Advisory Council. The committee advised the Bureau that a new edition would provide a useful and needed service to the state's mineral industry and its customers.

The information in the directory is available in the following formats: Microsoft Access for Windows 95; Microsoft Excel 3.0 for Windows; and comma-delimited text. Contact John Barnes to obtain digital or printed lists of companies, or for access to the directory via ftp.

The fifth edition of IC 54 is being prepared for printing as a book with accompanying commodity location maps and a large-scale state map. Anticipated publication is in late 1997.

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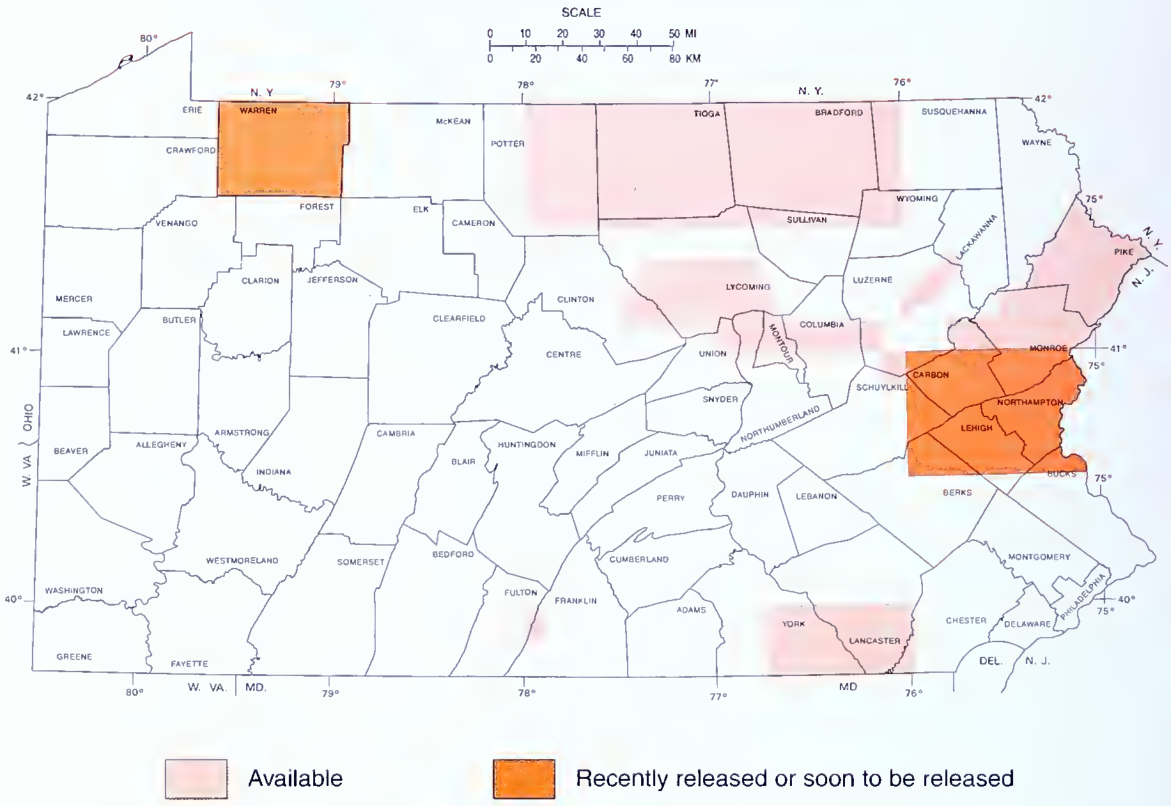

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Pennsylvania GEOLOGY

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CONTENTS

Doing more with *more*—the challenge of data accumulation and dissemination 1
Here a well, there a well 2
Fossils provide a Pennsylvania standard for part of Late Triassic time 8
New releases 15
Announcement 16

ON THE COVER

Geologists of the Department of Conservation and Natural Resources (DCNR) and the Department of Environmental Protection (DEP) explain the geological framework and plans for reducing acid mine drainage at a Tangascootack Creek acid drainage site to DCNR Secretary John Oliver (left) and Deputy Secretary Richard Sprenkle (wearing hooded jacket and standing beside State Geologist Donald Hoskins, both with backs to camera). See page 16 for a description of the cooperative project. Photograph by Jon D. Inners.

PENNSYLVANIA GEOLOGY

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Contributed articles are welcome. For further information and guidelines for manuscript preparation, contact D. M. Hoskins at the address listed above.
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STATE GEOLOGIST'S EDITORIAL

Doing More With *More*—the Challenge of Data Accumulation and Dissemination

The business of the Bureau of Topographic and Geologic Survey of Pennsylvania is to disseminate geologic and topographic information. Over a century ago, the Pennsylvania Legislature directed the Survey to provide "a clear insight into the character of [the state's] resources." One method by which we address this directive is to collect and preserve vast amounts of geologic and topographic data, carefully identified and organized by geographic location. From these data, we produce geological assessments and interpretations in order to distill the essential information needed by those concerned with understanding, exploiting, or managing the geologic resources of our commonwealth.

In these times when declining government resources require us to "do more with less" while data continually accumulate, managing geologic data is a challenging activity. Further complicating the managing of geologic data is the need to organize data collected not only at the earth's surface, but also below the surface. Additionally, geologists add the fourth dimension of geologic time to location and depth. Geologic time provides a necessary framework for scientific understanding that allows us to accurately interpret the geologic data we have collected.

The article herein about our Wells Information System, a geological database that supports our commonwealth's oil and natural gas resource industry, illustrates how we have begun to use new tools based on digital technology to rapidly disseminate the raw data we collect as well as to provide more complete geological assessments of the state's rocks and the resources they contain. Using these tools, we can now more effectively respond to daily requests for information about the geological aspects of our commonwealth's resources. We can now "do more with *more*" [data, that is], while more efficiently using our bureau's declining resources.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

HERE A WELL, THERE A WELL

by Kathy J. Flaherty and Cheryl L. Cozart
Pennsylvania Geological Survey

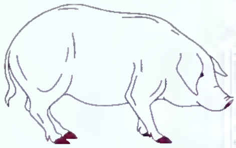
OLD McDONALD HAD A FARM, E-I-E-I-O. AND ON HIS FARM HE HAD A . . . WELL? E-I-E-I-O.

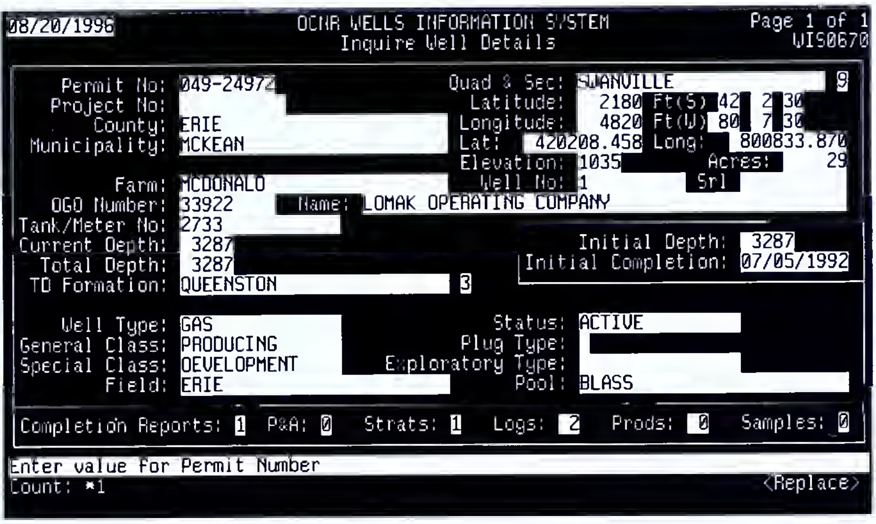
If Farmer McDonald lived in Erie County, Pa., and contacted the Pennsylvania Geological Survey to request details about the oil and gas well in his lower 40, he probably would expect us to take a few hours to search for that proverbial needle in the haystack. Actually, we would be able to give him the status of the McDonald #1 well within seconds. Now, that might not seem terribly impressive, but when you consider that there probably were more than 350,000 wells drilled in Pennsylvania since the Drake well in 1859, and more than 136,000 of those wells constitute the Commonwealth's modern database, surely one's eyebrow might raise just a tiny bit.

We can now answer Farmer McDonald's questions about his well in seconds because the Pennsylvania Geological Survey has a new, comprehensive oil and gas well database, the Wells Information System (WIS). In the WIS database, we store and organize the details associated with those 136,000+ drilled wells and more than 36,000 undrilled, canceled, void, or expired drilling permits. For the computer buffs in the audience, the database was developed in a commercial software package called Oracle, a relational database package that allows for the entry, storage, access, and analysis of data through any of a large number of linked data fields. The data are connected through some common factor, frequently, but not exclusively, the state-assigned permit number. In Farmer McDonald's case, all he knows about the well is that it is on his property in Erie County, yet we are able to find the well based only on his last name and the county in which he lives. In fact, we would have found Farmer McDonald's well if he had supplied details on any of the variety of searchable fields shown in Figure 1.

WITH A COMPLETION REPORT HERE, AND A STRATIGRAPHIC RECORD THERE . . .

In addition, by reading the summary near the bottom of the screen in Figure 1 (where his pig is looking), we can inform Farmer McDonald that we have one completion report, no plugging certificates (P&A), one interpreted stratigraphic formation record (STRATS), two





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08/20/1996            OCNR WELLS INFORMATION SYSTEM               Page 1 of 1
                          Inquire Well Details                        WIS0670

     Permit No: 049-24972                 Quad & Sec: SWANVILLE               9
    Project No:                             Latitude:   2180 Ft(S) 42  2 30
        County: ERIE                       Longitude:   4820 Ft(W) 80  7 30
  Municipality: MCKEAN                     Lat:    420208.458 Long:  800833.870
                                           Elevation: 1035       Acres:     29
          Farm: MCDONALO                     Well No: 1               Srl
    OGO Number: 33922       Name: LOMAK OPERATING COMPANY
 Tank/Meter No: 2733
 Current Depth:  3287                         Initial Depth:  3287
   Total Depth:  3287                    Initial Completion: 07/05/1992
  TD Formation: QUEENSTON              3

     Well Type: GAS                                Status: ACTIVE
 General Class: PRODUCING                      Plug Type:
 Special Class: OEVELOPMENT            Exploratory Type:
         Field: ERIE                                 Pool: BLASS

 Completion Reports: 1  P&A: 0   Strats: 1   Logs: 2   Prods: 0   Samples: 0

Enter value for Permit Number
Count: *1                                                           <Replace>
```

Figure 1. Inquire Well Details, one of numerous computer screens detailing a wide variety of information on more than 136,000 wells currently in the WIS database. The pig's snout points to the quick summary section that allows the user to jump to other screens in WIS.

geophysical logs (LOGS), no production reports (PRODS), and no drill cuttings or core samples on his well. Then, by selecting any of those summaries, we can view a supplementary screen that gives us complete information on the details housed there. For example, we can tell Farmer McDonald that his well was drilled in 1992 to the Upper Ordovician Queenston Formation at a total depth of 3,287 feet, had an after-stimulation open flow of 1,000 Mcfg (thousand cubic feet of gas) per day from the Lower Silurian Medina Group between 3,078 and 3,083 feet, and had a rock pressure of 850 psi (pounds per square inch) measured after 48 hours. A search of the stratigraphic interpretation screen shows, among other things, that the three formations in the Medina Group, the upper Grimsby Formation, middle Cabot Head Shale, and lower Whirlpool Sandstone, occur within the intervals 3,068–3,182 feet, 3,182–3,224 feet, and 3,224–3,231 feet, respectively. The geophysical logs screen indicates the types of logs and the intervals logged. Farmer McDonald's well file has a compensated density log and a dual laterolog that were run from 3,250 feet to 1,450 feet up the well bore.

Although the initial inquiry screen (Figure 1) indicates that there are no production records for Farmer McDonald's well, in reality the database contains production records for several years. The Commonwealth's oil and gas law mandates 5 years of confidentiality for production from all wells in Pennsylvania, and WIS is programmed not to reveal these data until the confidentiality period has expired. In

1998, the annual production for 1992 will become available, and the summary line on the inquiry screen (Figure 1) will show one production report for the McDonald well. In the meantime, because the oil and gas law allows reporting of recent production in aggregate statistics, we can point Farmer McDonald (or anyone else who is interested) toward the annual and cumulative production of the Blass pool in the Erie field. The McDonald well is just one of many in that pool. Farmer McDonald might be surprised to see that the the Blass pool has produced nearly 14,000 Mcfg since its discovery in 1958.

But *telling* Farmer McDonald the details of the well on his property is only one of our services. We are also capable of generating reports in either digital or hard-copy format for any and all wells in the system. Standard report forms already exist but, should a client wish, we can customize a report to suit specific needs. Looking forward, we hope to be able to place our WIS data on the Internet in the near future, where it will be available to anyone with access to the net.

HERE A WELL, THERE A WELL, EVERYWHERE A WELL? WELL!!!

A mapping system linked to the WIS database is used to create maps showing the locations of the wells and major geographical features. This mapping system is part of a geographic information system (GIS), a highly complex computer system that allows the user to capture, analyze, and display data in a spatial context. The GIS associated with WIS consists of Arc/Info and ArcView software. This software allows us to access and manipulate data stored in WIS to compile oil and gas well location maps. GIS requires spatial coordinates such as latitude and longitude in order to operate. Because oil and gas location data entered into WIS are given as footage offsets from nearby 2.5-minute latitude and longitude intersections, these offsets must first be converted to true latitudes and longitudes before the location of the well can be referenced in the GIS system. For example, Farmer McDonald's well is located 2,180 feet south of 42°02′30″ north latitude and 4,820 feet west of 80°07′30″ west longitude (Figure 1). In order to plot this well on a map, the location is converted through use of GIS software to 42°02′08.458″ north latitude and 80°08′33.870″ west longitude. The converted coordinates are also written back to WIS. Now we can produce a map of the area showing the location of Farmer McDonald's well (Figure 2, where his horse is prancing), and, in addition, provide the same data to anyone requesting information on the well (Figure 1).

So far, more than 54,000 wells have had offset latitudes and longitudes entered into WIS and converted to true latitudes and longitudes, and more are being entered and converted every day. At the time of this writing, locational details are complete for all wells in 19 counties (Figure 3), including Erie County, home of the McDonald #1 well, and, additionally, for all wells received by the Survey since January 1, 1986.

Figure 2 shows part of one type of oil and gas well location map currently being developed for sale to the public. Note that it has only county and municipality boundaries and names, roads, streams, and well locations and permit numbers (animal icons not included!). Different well symbols denote different types of wells. This map has a simple, open base, making it easy for a client to add geological information. A second type of well location map under consideration is shown in Figure 4. The McDonald #1 well is easy to spot (where his

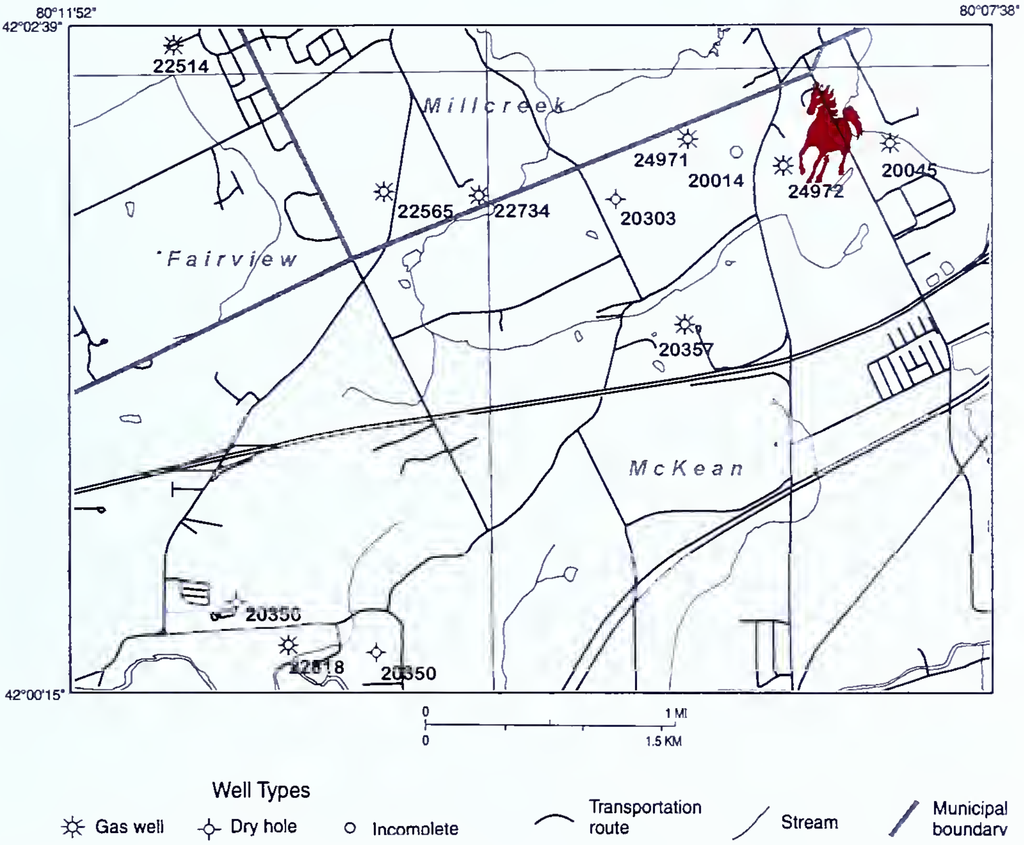


Figure 2. Part of the Swanville 7.5-minute base map showing the location of the well on Farmer McDonald's property (at the prancing horse). This map shows only limited geographic detail so that users can supply their own details.

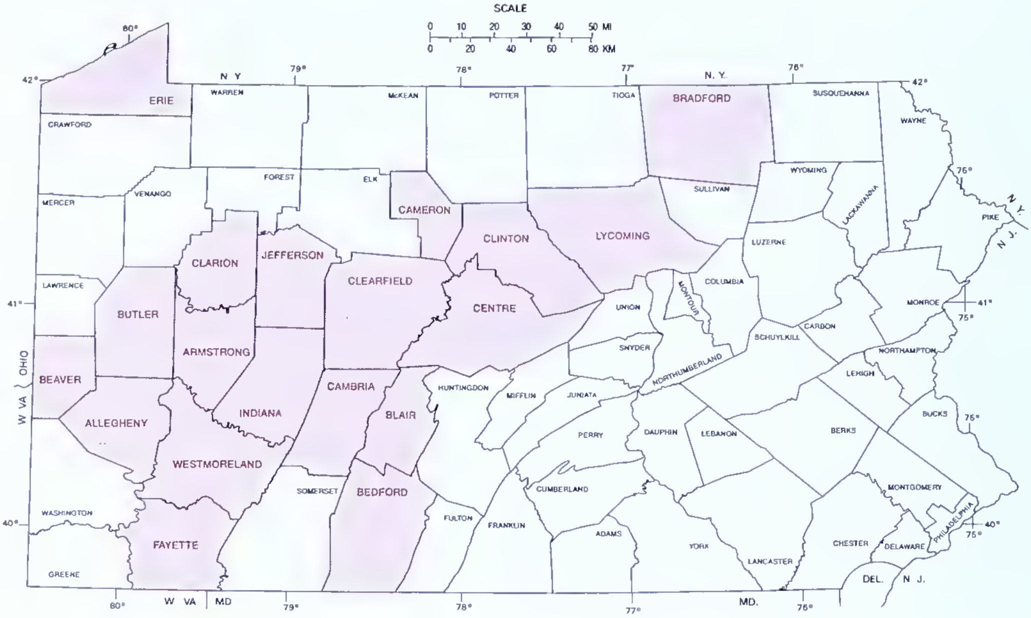


Figure 3. Map of Pennsylvania showing counties for which locational data are complete in WIS and GIS.

chicken is pecking) on this map. This type of map features the U.S. Geological Survey 7.5-minute topographic quadrangle map plus the oil and gas well locations. Such maps can be very useful to petroleum geologists interested in knowing what the landscape is like in their area of concern. U.S. Geological Survey topographic maps are now available on CD–ROM (as digital raster images) and show detailed topography, political boundaries, roads, waterways, cities and towns, and major cross-country transmission lines and pipelines. Trailer parks, houses, churches, schools, cemeteries, and many other cultural features can also be found on these images.

The Pennsylvania Geological Survey can customize other maps according to the client's specifications. We can produce a map showing all 3,231 wells in Erie County, such as that shown on the back cover. If Farmer McDonald were to request it, we could provide a map of wells that were drilled only to a certain rock formation, for example, a map of all wells drilled to Precambrian "basement," or a map of wells drilled within a particular field or pool, or a map of wells that produce only oil or only gas, or any combination of factors.

E-I-E-I-OOOOOOOOOOOO!

In addition to serving Farmer McDonald and the general citizenry, the WIS database and GIS systems are valuable research tools to scientists, engineers, and others involved with oil and gas drilling and

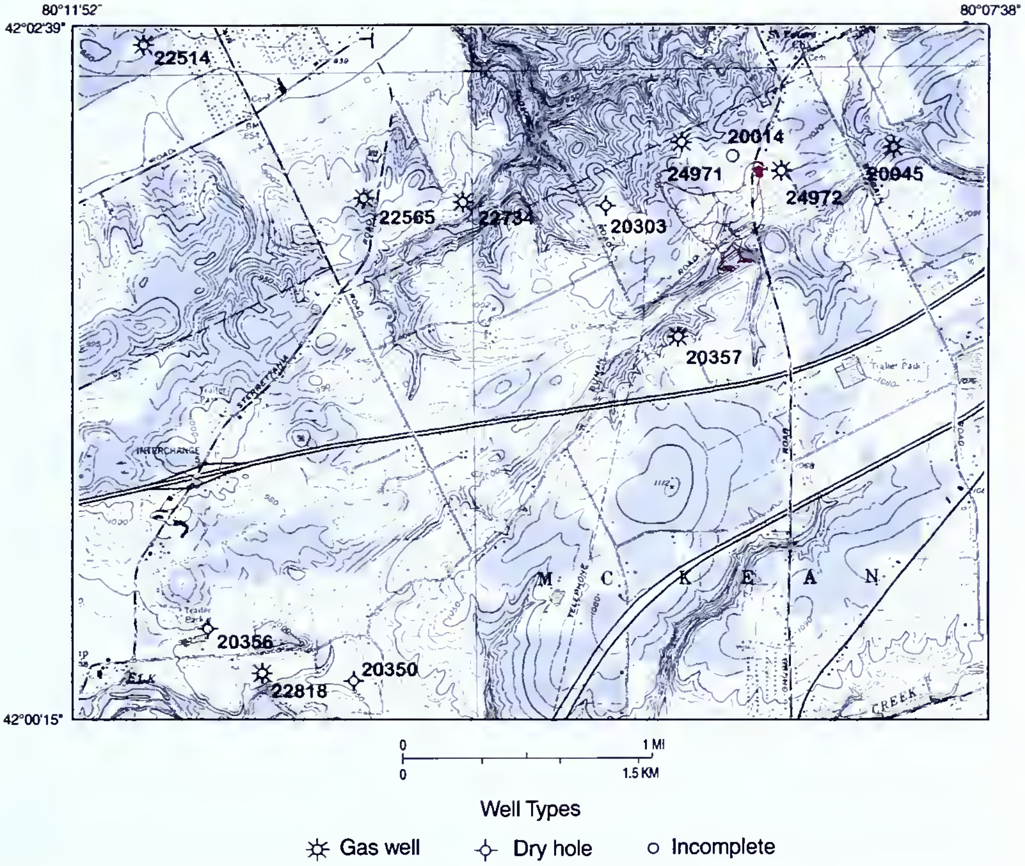
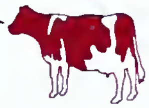


Figure 4. Gas wells plotted on a digital raster image of part of the Swanville 7.5-minute topographic map. The well on Farmer McDonald's property is highlighted by the chicken's beak. Compare this map with the map shown in Figure 2.

production, land use planning, environmental assessments, economic analyses, coal and other mineral industries, and many other earth-related activities. The systems provide needed information to the users quickly and in an organized format. Even Farmer McDonald will agree that implementation of WIS and GIS moo-oo-ove the Pennsylvania Geological Survey into the electronic information age.



E-I-E-I-O!!

A File Transfer Protocol (FTP) site has been established to allow users to log onto our server to extract database details and Arc/Info export files. For further information about this site and WIS, contact the Pittsburgh office of the Pennsylvania Geolcgical Survey at 400 Waterfront Drive, Pittsburgh, PA 15222–4745, telephone 412–442–4235.

Fossils Provide a Pennsylvania Standard for Part of Late Triassic Time

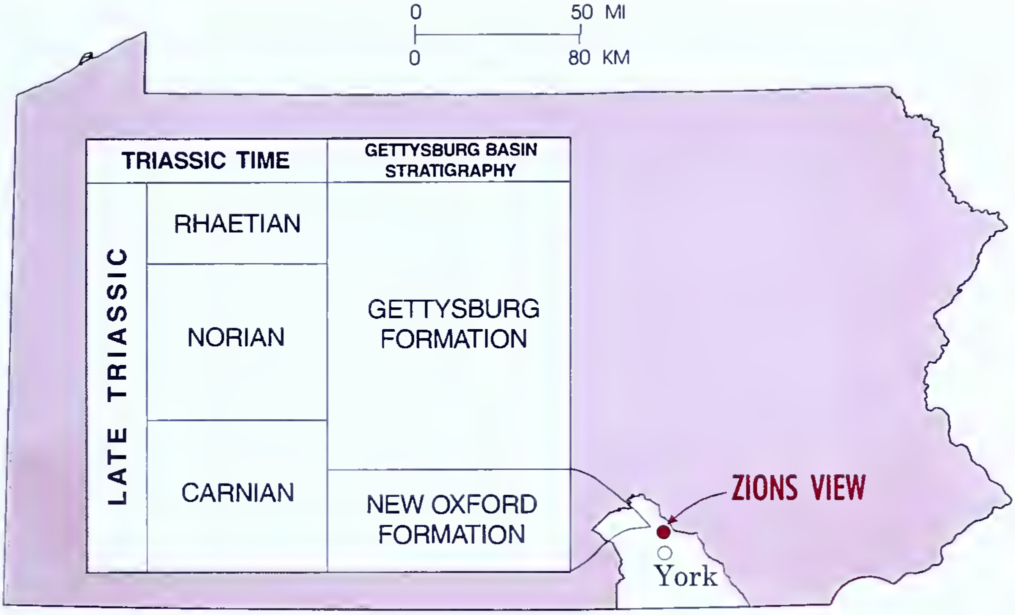
by Spencer G. Lucas
New Mexico Museum of Natural History and Science
Robert M. Sullivan
The State Museum of Pennsylvania

Fossils, and the changes they document in the history of life, provide the primary nonradiometric basis for subdividing geologic time. The different subdivisions of the geologic time scale—eons, eras, periods, epochs, ages, and biochrons (zones)—were first defined and continue to be refined by identifying particular kinds of fossils as characteristic of particular intervals of geologic time. Stratigraphic paleontologists, also called biostratigraphers, define and refine geologic time by collecting fossils very carefully, layer by layer. They then identify the fossils and determine which ones are restricted to a layer or a group of layers. This restriction becomes the basis for concluding that a particular fossil is characteristic of a particular time interval during which the animal (or plant) represented by the fossil lived.

Once the stratigraphic (temporal) distribution of a fossil is thus documented at a single location, biostratigraphers assume that occurrences of the fossil elsewhere are of the same geologic age as at that location. They can then correlate (establish equivalency in age and/or position) rock layers in various localities that contain the same kinds of fossils. This correlation is one of the fundamental goals of biostratigraphy.

To aid in such correlation, biostratigraphers prefer to identify a single location as the place where the rock layers and their fossils "define" a time interval. These places are called type sections. They are accessible, well studied, and very fossiliferous. The fossils found in a type section are distinctive and characteristic of an interval of time. For part of Late Triassic time (230 to 208 million years ago), Pennsylvania provides a standard at a type section at Little Conewago Creek in York County (Figure 1). This location has fossil vertebrates characteristic of the Conewagian, a short interval of Late Triassic time.

LOCATION. The fossil vertebrate locality on the eastern bank of Little Conewago Creek (Figure 2) is about 0.5 km (0.3 mi) southeast



TRIASSIC TIME		GETTYSBURG BASIN STRATIGRAPHY
LATE TRIASSIC	RHAETIAN	GETTYSBURG FORMATION
	NORIAN	
	CARNIAN	NEW OXFORD FORMATION

Figure 1. Location of the Little Conewago Creek site in York County, Pa., and summary stratigraphy of Upper Triassic strata in the Gettysburg basin.

of Zions View (UTM 4434357N, 349333E, zone 18). Fossils occur here in grayish-red micaceous shale, muddy sandstone, and clay-pebble conglomerate of the middle part of the New Oxford Formation (Glaeser, 1966). This locality is in the records of The State Museum of Pennsylvania (SMP) as locality 159.

HISTORY. Dr. Robert Spangler Stahle discovered SMP locality 159 in 1909, and his collecting efforts there between 1910 and 1912 were reviewed by Kochanov and Sullivan (1994). Edward Drinker Cope, the famous nineteenth century paleontologist, described dinosaur teeth from near Emigsville (Cope, 1878), about 5 km (3.1 mi) to the southeast of SMP locality 159, which were later referred by Hunt and Lucas (1994) to *Galtonia gibbidens*, a primitive ornithischian (bird-hipped) dinosaur. Wanner (1921, 1926) reported fish and phytosaur fossils from other localities 2 to 2.5 km (1.2 to 1.6 mi) to the northeast of SMP locality 159 along Little Conewago Creek. A second phase of collecting at SMP locality 159 took place in the early 1970's under the direction of Donald Hoff, former Earth Science Curator at The State Museum of Pennsylvania (Hoff, 1971). Early collections made at SMP locality 159 are at the Academy of Natural Sciences in Philadelphia, and the Princeton University Collection of Yale Peabody Museum, New Haven, Conn. (a specimen from which is on display at

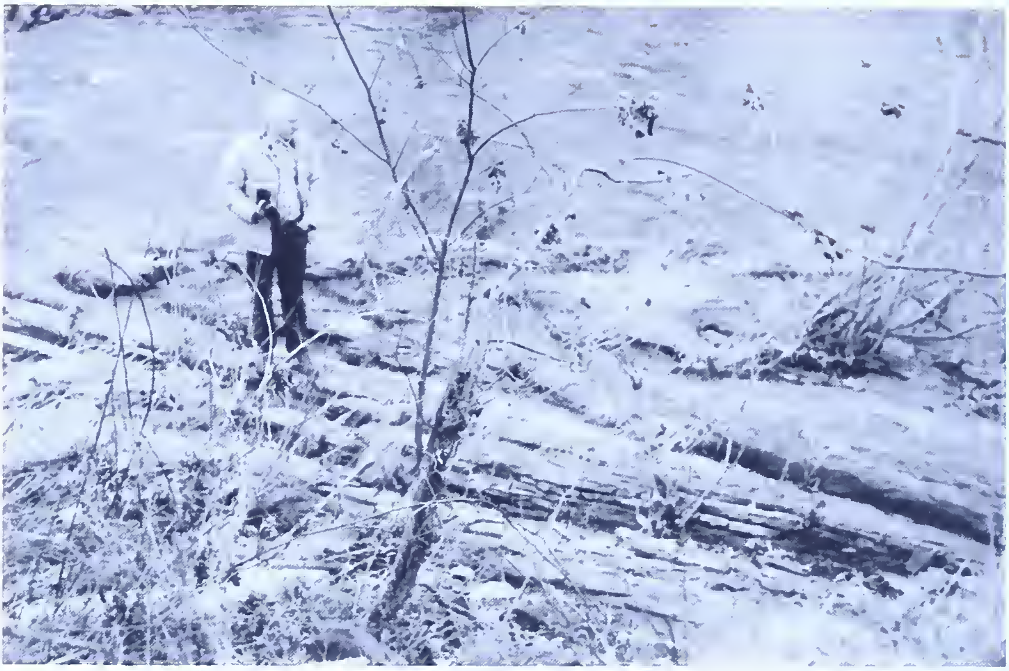


Figure 2. Zions View locality (SMP locality 159) on Little Conewago Creek, York County.

Rutgers University). The collection made by Hoff is curated at The State Museum in Harrisburg.

FOSSIL ASSEMBLAGE. Fossil conchostracans (clam shrimp) and unionid bivalves from SMP locality 159 have not been studied. Semionotid (primitive bony) fishes are represented by isolated scales, and vertebrate coprolites (fossil feces) are common. Most of the vertebrate fossils are of phytosaurs and encompass a wide range of isolated teeth and postcrania (skeletal elements other than the skull and jaws). Most significant is a skull (SMP VP–45) of a phytosaur recently described by Doyle and Sues (1995) and identified as *Rutiodon carolinensis* (Figure 3). Additional fossils found at SMP locality 159 include a skull (SMP VP–515) and other material of a metoposaurid amphibian (Figure 4) called *Buettneria perfecta* as redefined by Hunt (1993), not *Metoposaurus* as stated by Baird (1986).

ENVIRONMENT AND COMMUNITY. The conchostracans, bivalves, and primitive bony fishes (semionotids) indicate that deposition and fossil burial at SMP locality 159 took place in a freshwater lake. (These animals are characteristic of lakes.) The thinly laminated, grayish-red shales that contain many of the fossils at SMP locality 159 certainly

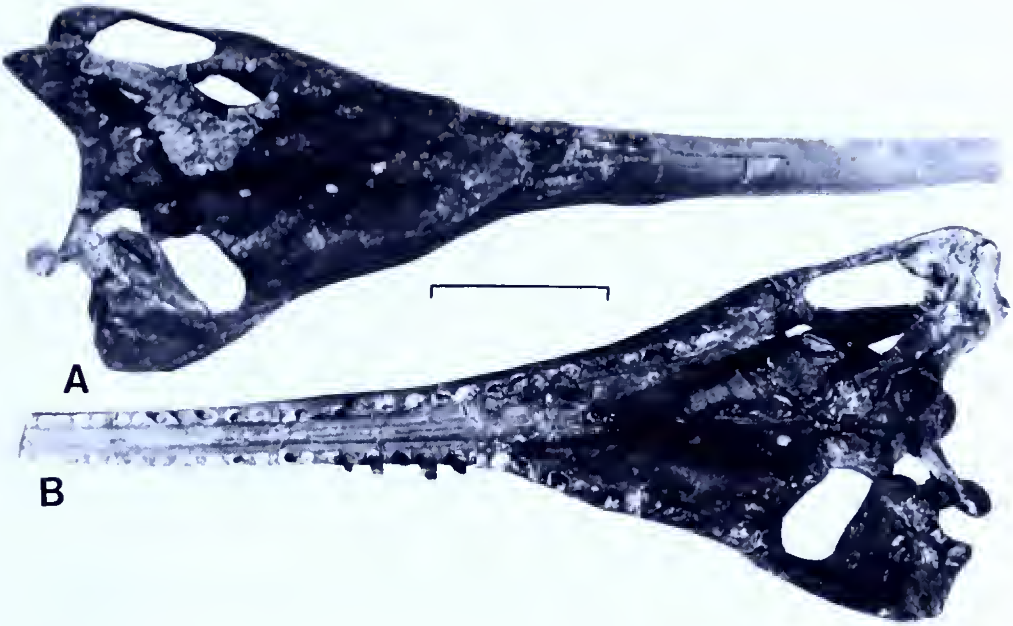


Figure 3. ***Rutiodon carolinensis*** **from Little Conewago Creek. A and B, skull (SMP VP–45), dorsal (A), and ventral (B) views. Bar scale is 10 cm long.**

correspond to thin layers of mud typically formed in lakes. However, lenses of muddy sandstone and conglomerate that contain some of the fossils indicate directional flow of water that would occur on beaches or at river mouths along the lake margin. Large reptiles (phytosaurs) and amphibians (metoposaurs) were water-bound animals that lived part of their lives in lakes and rivers and part on land.

The phytosaurs were an extinct group of crocodile-like reptiles (see Kochanov and Sullivan, 1994). Some phytosaurs were as much as 10 m (30 ft) long; all were predators who lived in and along the Late Triassic rivers and lakes.

Metoposaurs were one of the last families of an extinct group of ancient amphibians, the temnospondyls. A metoposaur looked something like a salamander, though some metoposaurs were as much as 2 m (6 ft) long. They too lived in and along Triassic rivers and lakes and probably were fish eaters.

The picture that we can draw of life along Little Conewago Creek 225 million years ago is of the margin of a lake, where clam shrimp, freshwater clams, and fishes lived. Large amphibians and crocodile-like phytosaurs hunted prey in this environment and were the largest animals on the landscape.

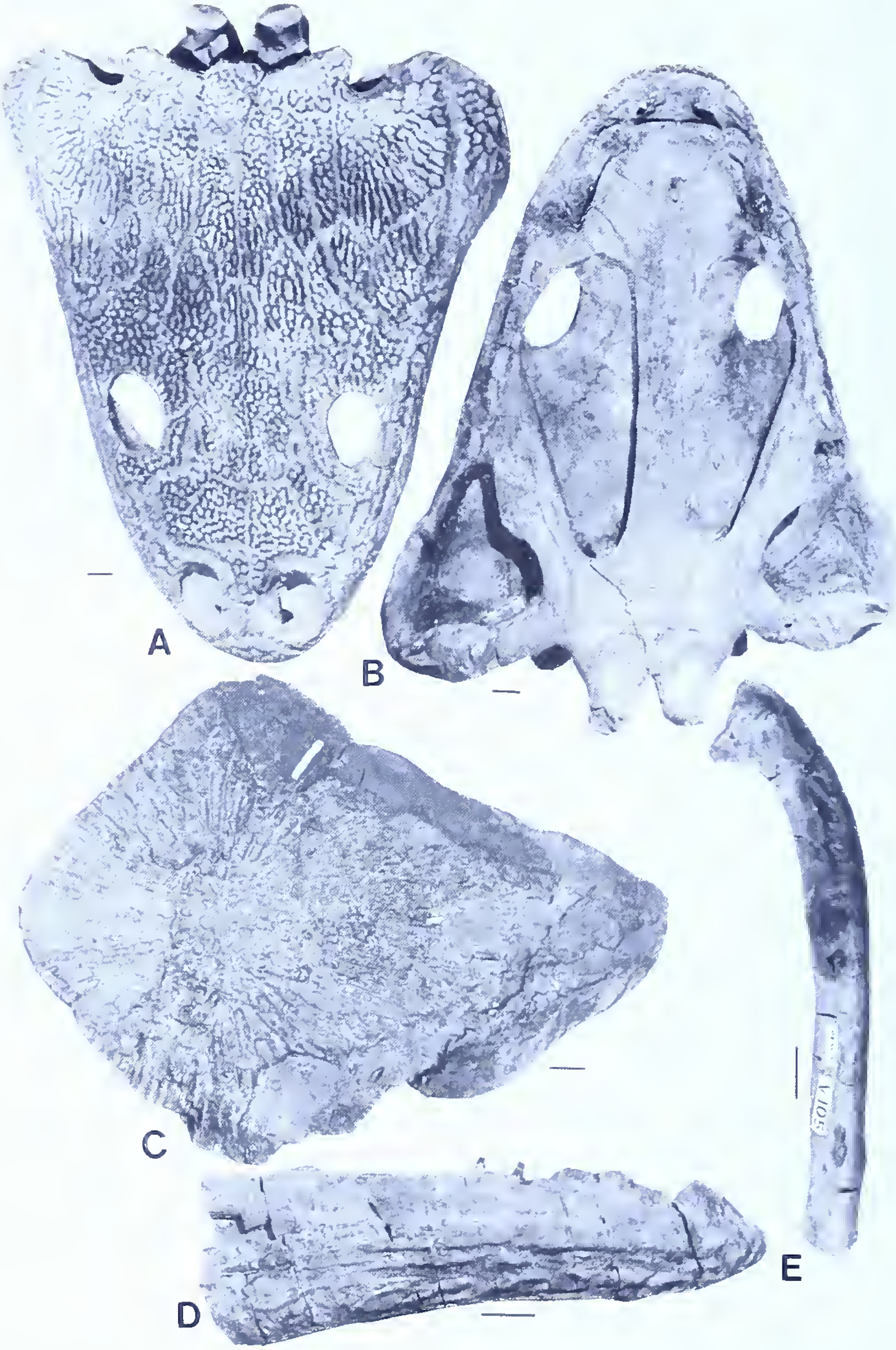


Figure 4. *Buettneria perfecta* from Little Conewago Creek. A and B, skull (SMP VP–44), dorsal (A) and ventral (B) views. C, interclavicle (SMP VP–515), ventral view. D and E, part of lower jaw (SMP VP–37), lateral (D) and occlusal (E) views. Bar scales are 2 cm long.

***RUTIODON CAROLINENSIS*: A LATE TRIASSIC INDEX FOSSIL.** Index, or guide, fossils can be of great utility to paleontologists and biostratigraphers in determining the relative age, or time interval, of a rock. Generally, fossils must meet two criteria before they can be considered index fossils. First, an index fossil must have a restricted temporal distribution. Second, an index fossil must have a wide geographic range, the wider the better. Clearly, a fossil that occurs widespread through geologic time, or conversely has a limited geographic occurrence (i.e., is known from only a single locality), has little use in determining precise relative age, as it is of little use in correlation from one place to another. The phytosaur genus *Rutiodon* is known solely from strata of late Carnian age (about 225 million years ago) both in the eastern and western United States (Ballew, 1989). The species *Rutiodon carolinensis*, originally described from fossils collected in the Newark Supergroup of North Carolina, has a very restricted time distribution and a relatively wide geographic range within the strata of the Newark Supergroup (North Carolina, Pennsylvania, and New Jersey). *Rutiodon carolinensis* appears to be a good candidate for an index fossil for the East Coast late Carnian.

Locally, the Lockatong and New Oxford Formations have produced phytosaur material referable to *Rutiodon carolinensis.* In addition, other fossil vertebrates have been discovered at separate localities within these two formations and others. Some fish (*Carinacanthus jepseni*), cynodonts (*Boreogomphodon jeffersoni*, *Mircocodom tenuis*, and *Dromotherium silverstri*), nondinosaurian archosaurs (*Doswellia kaltenbachi* and *Eosuchus olseni*), dinosaurs (*Pekinosaurus olseni* and *Galtonia gibbidens*—Pennsylvania's only known dinosaur), and the flying eolacertilian (*Icarosaurus siefkeri*), a lizard-like creature, are known solely from strata that are late Carnian in age, which vertebrate biostratigraphers call the Conewagian.

CONEWAGIAN. Huber and others (1993a, b) and Lucas and Huber (1993) argued that fossil vertebrates from the Newark Supergroup (Triassic-Jurassic rocks deposited in rift basins from Nova Scotia to South Carolina) define four intervals of Late Triassic time. They named the next to the oldest of these intervals the Conewagian for the fossil locality near Zions View. The phytosaur *Rutiodon carolinensis* and its association with the metoposaur *Buettneria perfecta* characterizes Conewagian time. Fossils and rocks of this age are present throughout the Newark Supergroup basins. The Conewagian type fauna thus helps biostratigraphers draw a time line through the Upper Triassic rocks of eastern North America. This time line can be used to order geological events and thus contribute to a better understanding of the Late Triassic geological and biological history of eastern North America. The Pennsylvania type section near Zions View thus contributes in its own small, but significant, way to the biostratigraphy of the Late Triassic.

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Upper and Lower Middle Devonian Stratigraphic Synthesis

The Pennsylvania Geological Survey has released **Open-File Report 96–47, Upper and Lower Middle Devonian Stratigraphic Synthesis, Central Appalachian Basin of Pennsylvania.** The report, by Charles A. Ver Straeten, is a new, detailed stratigraphic synthesis of Deerparkian- to early Cazenovian-age strata in Pennsylvania. These strata make up the Ridgeley, Esopus, Schoharie, Palmerton, Buttermilk Falls, and Needmore (Onondaga) Formations; the lower part of the Marcellus Formation; and the Turkey Ridge Member of the Mahantango Formation. A statewide and regional outcrop study, utilizing high-resolution event and sequence stratigraphic methods, permitted the author to recognize and correlate small-scale (submember- to bed-level) units across large areas of the basin.

Open-File Report 96–47 may be purchased for the prepaid copying and shipping costs of **$2.00 plus $0.12 state sales tax** for Pennsylvania residents. Please see the following announcement for instructions on ordering.

Independent Steam-Electric Plants in the Anthracite Region

Open-File Report 96–50, Independent Steam-Electric Power Plants in the Anthracite Region, NE Pennsylvania: Site Geology, Coal-Refuse Bank Utilization, and Environmental Benefits, has been released by the Pennsylvania Geological Survey. The well-illustrated report, authored by Jon D. Inners, William E. Edmunds, and James A. LaRegina, contains discussions of various geological, engineering, and environmental aspects of the Anthracite region's nine cogeneration facilities and small power plants. It includes a summary of plant specifications and geologic maps (taken mostly from published sources) of the various sites.

Open-File Report 96–50 may be purchased from the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–

8453, for the prepaid copying and shipping costs of **$3.00 plus $0.18 state sales tax** for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania.* The report may be examined in the library of the Pennsylvania Geological Survey, Evangelical Press Building, Second Floor, 1500 North Third Street, Harrisburg, and in the Pittsburgh office of the Survey at 500 Waterfront Drive.

For further information on open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–787–6029.

ANNOUNCEMENT

Cooperative DCNR–DEP Watershed Restoration Project

The Tangascootack Creek watershed, north of Lock Haven, is the site of a joint effort between the Pennsylvania Department of Conservation and Natural Resources (DCNR) and Department of Environmental Protection (DEP) to reduce acid mine drainage and restore a watershed for recreational purposes. Coal mining in the watershed dating to the 1850's changed the groundwater-flow paths and exposed coal- and clay-bearing rocks that, together, produce acid mine drainage affecting the south fork of the creek.

Through the partnership project, geologists of DCNR and DEP are collecting geologic and hydrogeologic data. DCNR's Bureau of Topographic and Geologic Survey is using the data to prepare a new, detailed geologic map of the area. The geologic map information will be used in an assessment of the coal resources and to plan for restoration of the creek's water quality through remining and reclamation of exposed acid-producing rocks. The detailed geologic map will establish the total remaining coal resources. In remining, the drainage from old underground mines can be reduced and the land surface restored.

DCNR Secretary John Oliver and Deputy Secretary Richard Sprenkle visited the site (see cover) in the Tangascootack watershed to assess the plan of work and progress by the Bureau of Topographic and Geologic Survey in providing the geologic information needed by DEP to proceed with planning restoration of the watershed.

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IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY
TOPOGRAPHIC MAPPING
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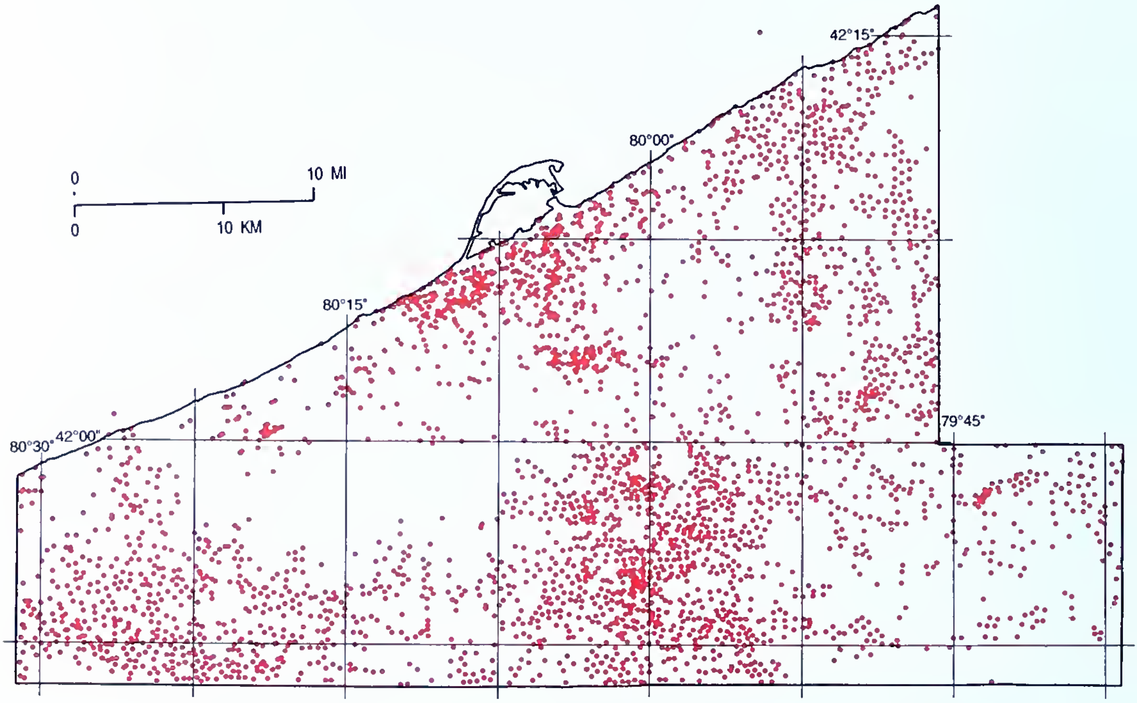
OIL AND GAS WELLS IN ERIE COUNTY

The map shows all 3,231 known oil and gas wells in Erie County. Wells were being drilled in the county as long ago as 1860, and the wells illustrated here have details of location, drilling, and completion in the Bureau's Wells Information System. (See article on page 2.)



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Pennsylvania GEOLOGY

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CONTENTS

Map 61 and more—"on the WEB!" 1
The mummy's shroud 2
A tale of two valleys 9
New releases 14

ON THE COVER

The "mummy," an unusually shaped pinnacle of dolomite in a sinkhole in the Cambrian-age Ledger Formation of York County (see article on page 2). Photograph by William E. Kochanov.

PENNSYLVANIA GEOLOGY

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VOL. 28, NO. 1/2 **SPRING/SUMMER 1997**

STATE GEOLOGIST'S EDITORIAL

Map 61 and More—"On the WEB!"

Map 61, a very popular, out-of-print publication of the Pennsylvania Geological Survey, is now "on the web." Map 61, an unbound report published by the Survey in 1981, consists of 624 page-sized geologic maps. It is one of the most useful and most often requested reports of the Survey. Easily photocopied, the page-sized maps are frequently made part of reports prepared by other geologists. But, because the edition is now sold out and personal copies have became more and more dog-eared from use, we repeatedly are requested by clients to reprint Map 61. Unfortunately, resources for reprinting are not available.

To address the problem, we investigated the possibility of republication via digital technology. We have found a solution that benefits our clients in two ways! One, the maps of Map 61 are now available to anyone who has access to a computer that is connected to the Internet. Two, it's free! There will be no charge to anyone for downloading and printing personal copies of any of the individual maps.

If the digital republication process proves successful, we will use this technology to reprint other out-of-print reports, including such popular reports as G 40, *Fossil Collecting In Pennsylvania,* and G 33, *Mineral Collecting in Pennsylvania*. They, too, will be **free** to visitors to our WWW site.

A deficiency of the publishing of out-of-print reports in this fashion is that each page must be separately printed by the user. However, the user needs to print only the pages of interest, not an entire book. Also, with respect to Map 61, some of the maps printed via the Internet will not show all lines, because some very thin or faint lines are not captured during the computer scanning process. We expect that this problem can be rectified in the future.

Please visit our WWW site at <http://www.dcnr.state.pa.us/topogeo/index.htm> and let us know if this new way of providing you with out-of-print information is acceptable. We desire to keep useful and popular publications available to all who are interested. But we need your comments to determine if you will accept information using digital technology. Call, write, or send e-mail to hoskins.donald@a1.dcnr.state.pa.us, but please let us know!

Donald M. Hoskins

Donald M. Hoskins
State Geologist

THE MUMMY'S SHROUD

by William E. Kochanov
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PROLOGUE. The story behind the discovery of a unique specimen or geologic feature generally does not fall into the category of an "Indiana Jones" type of adventure. The thrill of discovery usually results in an outburst rarely heard by the public. Quite commonly, it is preceded by an expletive accompanying the last whack of a hammer, a bruised knuckle, or a tear in a new pair of jeans.

I made such a "thrilling" geological discovery in the spring field season of 1994 during a routine roadside survey of sinkholes in the West York area of York County. What caught my eye was a large area of disturbed ground between U.S. Route 30 and the rear parking lot of the Manchester Mall. Past experience has shown that these disturbed sites are commonly the result of recent sinkhole activity and can provide valuable information about subsidence history in a given area caused by the dissolution of carbonate bedrock. True to expectations, a thorough survey of the drainage area and the adjoining embankment along U.S. Route 30 revealed 24 sinkholes (Figure 1).

THE "MUMMY" SINKHOLE. Within one of the sinkholes was a group of thinly spired bedrock pinnacles. One of the pinnacles resembled a wrapped mummy that would have fooled any embalmer from the Luxor necropolis (Figure 2 and cover).

From the vantage point along the rim of the sinkhole, there appeared to be a black coating on the surface of some of the pinnacles (Figure 3). This warranted a closer look, so it was necessary to climb down into the sinkhole. (NOTE: *Climbing down into a sinkhole can be very dangerous.* Sidewalls and open passages are typically very unstable and can collapse without warning. Personal examination of sinkholes is not recommended.)

OBSERVATIONS. The size of the sinkhole was not extraordinary. It was approximately 15 feet in diameter and about 15 feet in depth. A

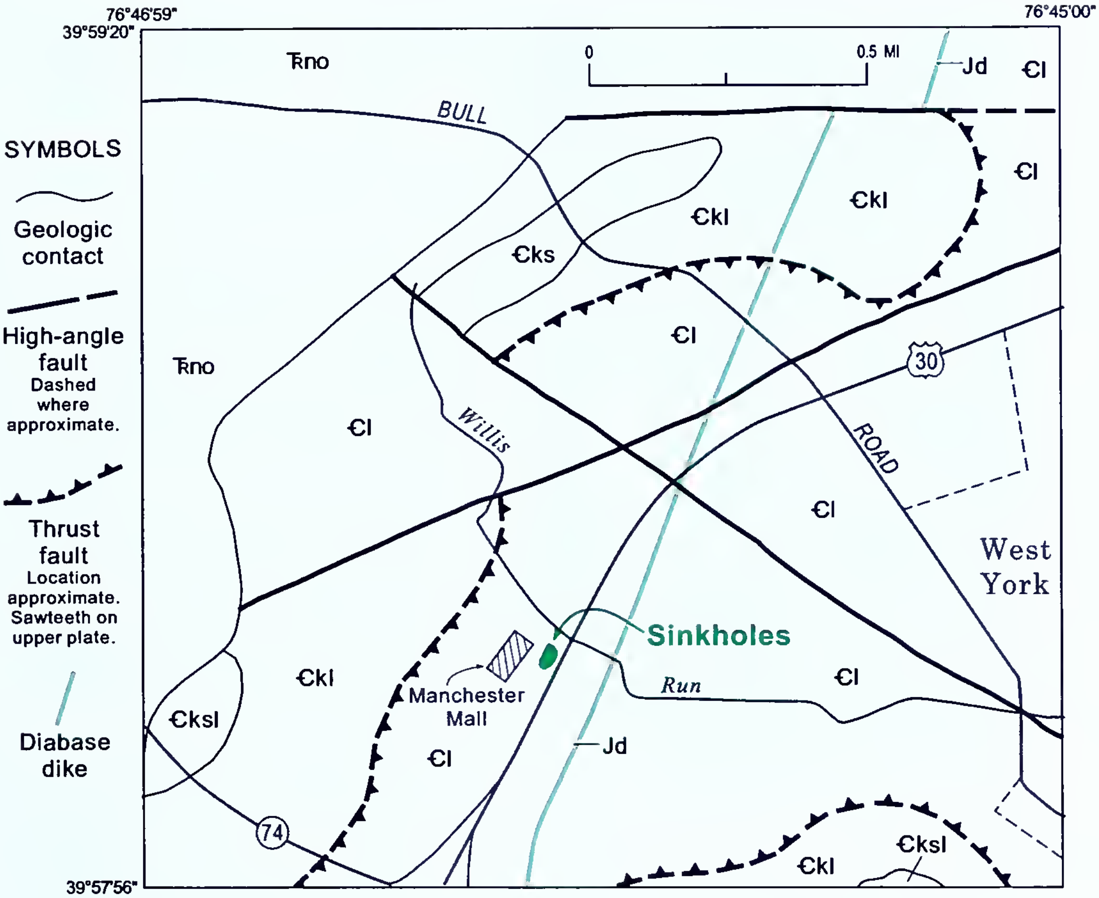

Figure 1. A geologic map of the West York area showing the location of the group of sinkholes where the "mummy" was found (geology modified from Wilshusen, 1979). Geologic units are as follows: Jd, Jurassic-age diabase; Ꞧno, Triassic-age New Oxford Formation; €l, Cambrian-age Ledger Formation; €ks, Cambrian-age Kinzers Formation, shale; €kl, Kinzers Formation, limestone; €ksl, Kinzers Formation, sandy limestone.

concrete plug was observed at the base, indicating that the sinkhole had been repaired in the past.

A closer examination of the crust on the pinnacle revealed that it was approximately 1 cm in thickness and that its color ranged from orange to red brown to black. The colors identified it as a variety of iron oxide. The crust was very porous and had no apparent crystalline structure.

At the time of the investigation, parts of the surface of the pinnacles were uncoated. It was assumed that the iron shroud covered

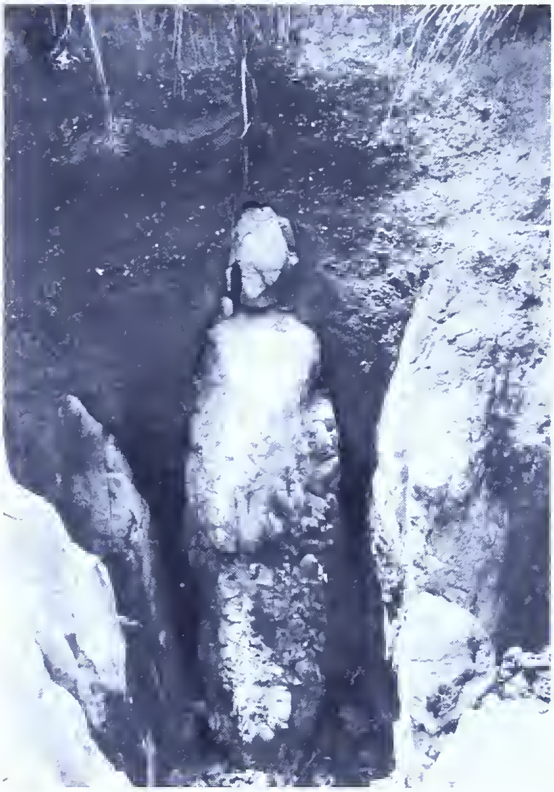

Figure 2. The "mummy," a pinnacle of dolomite of the Ledger Formation.

the entire surface of the bedrock at one time. Storm water flowing into the open sinkhole from a nearby drain probably removed sections of the iron oxide crust.

Where intact, the thickness of the coating remained relatively constant. It was thicker, however, in the weathered, recessed areas of the bedrock surface.

The exposed bedrock had a moderately weathered surface. Carbonate dissolution had etched the surface of this withered "mummy" along the layered (bedding) surfaces and the many crisscrossing fractures. When rubbed by hand, the surface of the weath-

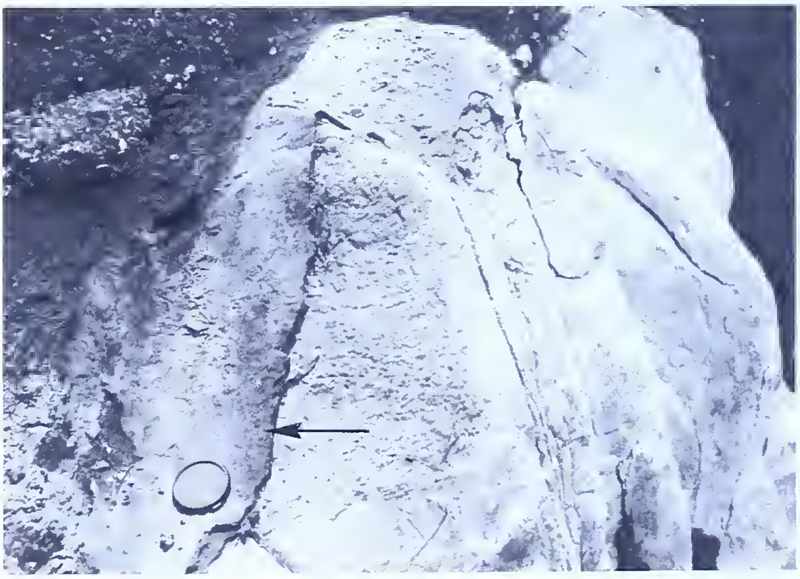

Figure 3. Bedrock surface showing part of the iron oxide crust (arrow). The 60 mm lens cap provides scale.

ered bedrock flew off in a cloud of powder. A weak fizz from a drop of diluted hydrochloric acid applied to a freshly broken piece of the light-gray bedrock identified it as dolomite.

The side walls of the sinkhole provided an excellent cross-sectional view of the overburden material. Overlying the pinnacles was a dark-reddish-brown to orange-brown sandy clay that contained well-defined layers of sand, pebbles, and rock chips. The pebbles were primarily subrounded white quartz and light-gray to buff sandstone and quartzite. The rock "chips" were buff siltstone averaging about 1 inch in size with some imbrication (overlapping at an angle). Overall, the sediment occurred in well-defined layers (Figure 4).

INTERPRETATIONS. How did the mummy's shroud form? Where did the iron come from?

The source of sediment. In general, the material overlying the bedrock was derived from the Triassic New Oxford Formation, which occurs to the northwest of the sinkhole site (Figure 1). The New Oxford is described as red-brown shale and mudstone interbedded with red to gray to buff sandstone, arkosic sandstone, and quartz conglomerates (Stose and Jonas, 1939; Wilshusen, 1979). The conglomerates contain rounded quartz and quartzite pebbles (Stose and Jonas, 1939). The materials that make up the overburden in the sinkhole are lithologically similar to the units observed in the New Oxford Formation.

The New Oxford Formation is topographically higher than the sinkhole site. Present drainage patterns allow Triassic sediment to

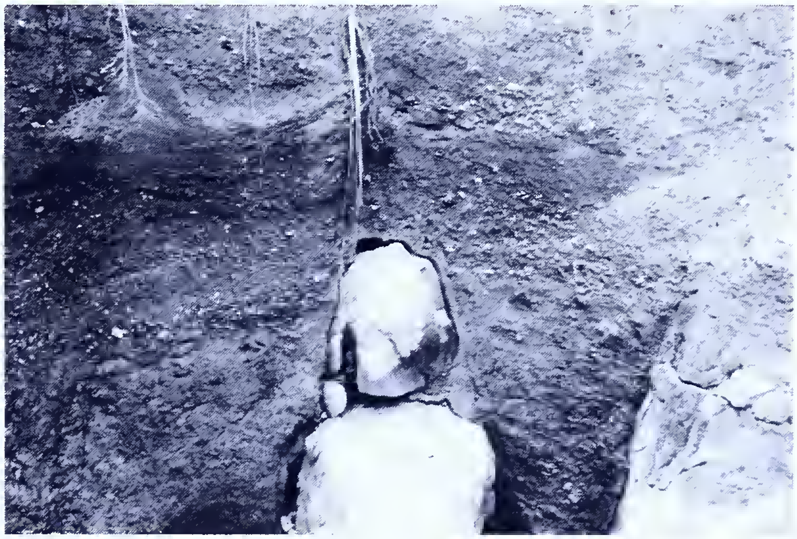

Figure 4. Pebbly zone in stratified fill above the head of the "mummy."

be carried from the north and be deposited as the primary fill material within the sinkhole.

The makeup of the unconsolidated material overlying the dolomite of the Ledger Formation suggests an alluvial (stream) environment of deposition. The imbricated rock chips indicate that the current of the stream was strong enough to align the clasts (individual pieces) parallel to the direction of flow. In some places along the side wall of the sinkhole, the pebbly material appeared to be comparable to lag deposits identified with stream channel deposits. These deposits generally contain the coarser sediments, which are typically found at the base of a stream channel. In the pebble lag deposits, most of the finer grained sediments (silt and mud) have been removed by the moving water, leaving the coarser material behind.

Geochemistry. In the earth cookbook, water is the main ingredient. It moves through the soil, reacts with different minerals, and helps to form new compounds. In the "mummy" sinkhole, the sediment overlying the bedrock is red brown. This color is typical of the New Oxford Formation and Triassic-aged sedimentary rocks in general. The color is indicative of oxidized iron. The iron that gave the Triassic rocks their red color was probably recycled from older rocks and later oxidized after the sediment was deposited during the Triassic Period. Present-day erosion of the Triassic bedrock to the northwest is a modern cycle of sediment deposition. In this cycle, the deposition is within the sinks and surface depressions of the karst landscape.

As infiltrating water reacts with minerals, different components are released in the form of ions. Iron ions released from the Triassic source rock become mixed with the percolating water and form new compounds, such as iron hydroxides, as the water makes its way to the water table. The mixing process and formation of new compounds are dependent upon the amount and rate of water percolating through the soil. The slower the movement through the sediment, the longer the water is in contact with the different minerals, thus affecting the formation of new compounds. Other variables, such as oxygen levels, temperature, pH, and bacterial activity, also affect the local groundwater chemistry.

The transient iron minerals may or may not make it to the water table. They may become attached to the surface of clay particles, to other sediment, or to the bedrock surface.

Perhaps nearby Willis Run has played a major role in mobilizing the iron compounds. In this scenario, the sediment is transported by the stream and fills in the existing sinkhole. In the floodplain of Willis Run, the water table fluctuates with changes in seasonal precipitation or with individual rain events. When the water table is above the bedrock surface, the iron compounds that were adhering to the sediment are mobilized. As the water table slowly drops, the iron compounds move with it, perhaps being relocated onto other sediment particles or perhaps making their way to the dolomitic bedrock.

It was noted above that the bared surface of the weathered dolomitic bedrock rubbed off in a cloud of powder. This implied that the carbonate portion of the dolomite had been removed over time, leaving behind the more insoluble portion. The rind of the weathered carbonate bedrock is very porous. The iron oxide coating was also noted to be very porous. It is probable that the iron compounds in ionic form filled in the pore spaces of the weathered bedrock rind. As the water table dropped, these iron compounds remained in the interstitial area between the insoluble grains. As the environment changed from a reducing (below water) to an oxidizing (above water) one, the iron compounds were left, relatively, high and dry. The iron minerals became dehydrated (lost water) and were then oxidized, forming a layer of iron oxide crust on the dolomite pinnacles. Repetitive cycles of reducing and oxidizing environments coupled with a fluctuating water table could account for the thin, repetitive laminae of iron oxide over a period of time.

Alternatively, iron minerals could have been released from the Ledger Formation during the dissolution process. Residuum (the residue remaining after rock has undergone the weathering process) from carbonate bedrock typically contains a small percentage of iron.

If iron is released through the dissolution of Ledger dolomite, perhaps it is oxidized relatively quickly and remains adhered to the surface of the bedrock, filling in the pores left by the vacating carbonate ions. Laminae of iron oxide form as succeeding layers of carbonate bedrock are removed.

MUMMY WRAP-UP. The one factor that has not been discussed in detail is the length of time needed to produce the “mummy’s shroud.” If each iron oxide lamina is related to seasonal variations in precipitation and corresponding changes in groundwater levels and local chemistry, then the layering may have been built up over a relatively short period of time. Perhaps the formation of the iron oxide crust coincided with the redistribution of stormwater as a result of the construction of the Manchester Mall.

Lesley (1892, p. 433) observed that the rate of deposition of limonite (iron oxide) in cavities can be quite rapid. One example was cited from the Bennington shaft near the Allegheny mountain summit tunnel of the Pennsylvania Railroad in Blair County, where "'...the pump column' receives from the mine water *one inch* of such deposit [limonite] each year, supplied by the decomposition and oxidation of carbonate iron ore [siderite] balls in the roof shales of the Miller coal bed."

Much less dramatic examples of rapid iron oxidation can be observed in the yellow to red coloration of streams in areas of Pennsylvania that have been mined for coal.

Another possibility is that the iron oxide crust forms at a rate that coincides with the dissolution of the dolomite bedrock. As the carbonate bedrock is removed through chemical dissolution, a porous framework of residual material remains, providing a medium to which the iron oxide minerals can adhere. Carbonate dissolution rates depend upon climate and interrelated geochemical factors. A general dissolution rate of 30 mm (slightly more than an inch) per 1,000 years is given for carbonate rocks in Centre County (Parizek and White, 1985). With this as a general guide, one can infer that the 0.25- to 0.5-inch crust may have taken 250 to 500 years to develop.

In any case, we are looking at a localized event at one point in time. It would be interesting to come back to the same spot 1,000 or even 10,000 years from now and see if the "mummy" remains standing, and whether it has a thicker "shroud."

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A TALE OF TWO VALLEYS

by Gary M. Fleeger
Pennsylvania Geological Survey

It was the coldest of times. It was the wettest of times. It was also a time of change.

Diversions in the courses of drainage caused by glaciation have been recognized in the area of Butler, Mercer, and Lawrence Counties in Pennsylvania since the late nineteenth century (Preston, 1977). Most of the known major drainage changes probably occurred during the older of the four major glaciations that covered the area (Fleeger, 1984). No permanent drainage changes associated with the youngest and most recent glaciation (Kent) have been previously documented (Preston, 1977). This may be because, based on available evidence, it appears that with each successive glaciation, drainage diversions became smaller and involved lower order streams. Hogue Run, in northwestern Butler County, is an example of a small stream diversion caused by the youngest (Kent) glaciation.

A drainage anomaly exists along Hogue Run (Figure 1). It flows through the headwater areas of two adjacent, and formerly separate, valleys. Topographic orientation, best seen by observing the 1,300-foot topographic contour line on the Slippery Rock and Prospect 7.5-minute-quadrangle maps, suggests that streams should flow northwest toward Slippery Rock Creek. However, Hogue Run flows northeast across a broad valley, across the regional alignment of valleys, through a small gorge, and into an adjacent valley. There, it turns 90 degrees to the northwest and flows toward Slippery Rock Creek.

PREGLACIAL DRAINAGE. Topographic orientation suggests that preglacial Black Run originated south of the glacial boundary, southwest of West Liberty. Several tributaries joined and flowed northwest to preglacial Slippery Rock Creek (Figure 2). Likewise, Hogue Run, in the adjacent valley to the east, flowed toward Slippery Rock Creek, parallel to Black Run.

Near the headwaters of Black and Hogue Runs, most of the divide between these two streams exceeded 1,300 feet in elevation.

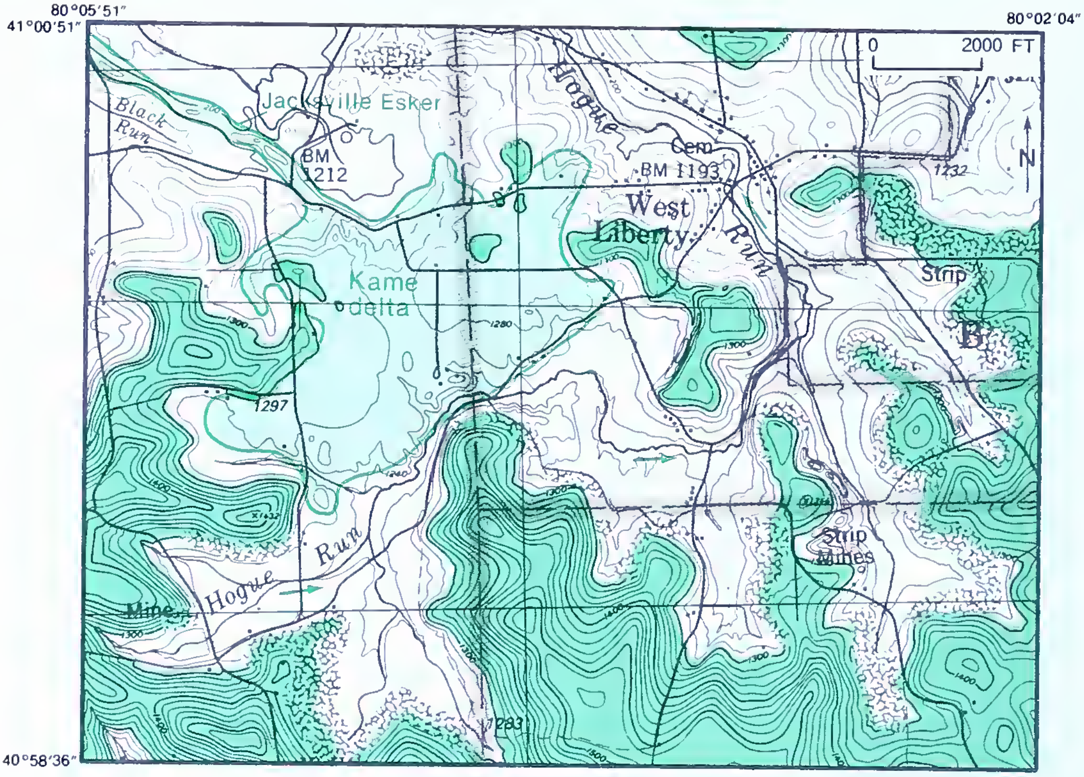

Figure 1. The present topography and features in the area of Hogue Run. The darker color indicates areas that are greater than 1,300 feet in elevation (base map from U.S. Geological Survey Butler County topographic map, scale 1:50,000).

However, at one point (site A on Figure 2), the present topography suggests that the preglacial divide was below 1,300 feet.

KENT GLACIATION. The Kent glacier advanced into the area about 23,000 years ago (White and others, 1969) and blocked northwest-flowing streams, forming proglacial lakes in their valleys. The lake in the Black Run and Hogue Run valleys was part of Lake Edmund (Preston, 1977). During the Kent advance (Figure 3), a meltwater stream flowing in a tunnel beneath the glacier deposited a sinuous ridge of sand and gravel, known as an esker. This esker, the Jacksville Esker (also known as the Miller or West Liberty Esker), formed, more or less, in the position of the lower reaches of preglacial Black Run (Fleeger, 1986). Where the subglacial stream discharged from the tunnel into Lake Edmund in the upper reach of the Black Run valley, it built a kame delta (delta in contact with glacial ice).

The kame delta completely blocks the preglacial Black Run valley with about 177 million cubic yards of sand and gravel in a 50-

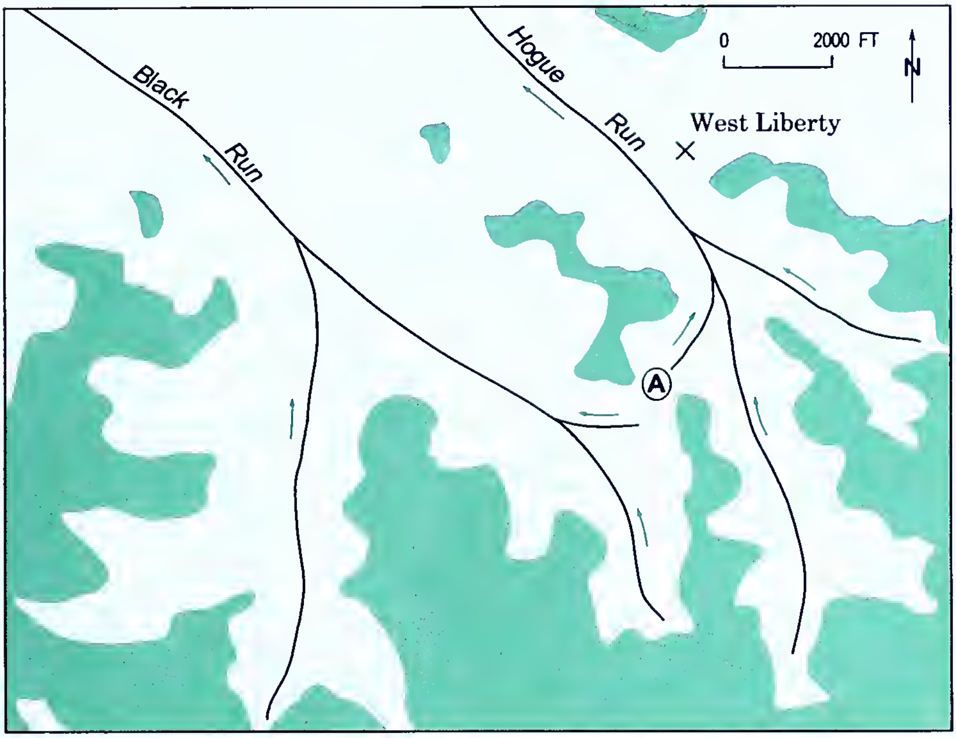

Figure 2. The preglacial configuration of Black and Hogue Runs indicates that the present headwaters of Hogue Run were originally drained by the upper part of Black Run. Areas that are greater than 1,300 feet in elevation today are shown in color.

foot-high, 1.5- by 0.75-mile mass. The topography of the ice-contact side, the north side, is hummocky, probably due to collapse after the supporting glacier retreated. The south side is a slope that extends smoothly to the lacustrine plain of the former lake bottom.

When the Kent glacier melted, Lake Edmund drained from the area and from Hogue Run valley. However, the kame delta continued to dam the upper Black Run area, and it remained a lake (Black Lake). Overflow from Black Lake drained through an outlet at the low point on the eastern side of Black Run valley, flowed into Hogue Run valley, and then flowed to Slippery Rock Creek (Figure 4). Gradually, the lake overflow eroded through the divide, Black Lake was drained, and a diverted stream flowing northeast was established.

The elevation of the spillway at Black Lake must have been slightly below 1,280 feet. Had it been higher than 1,280 feet, Black Lake would have drained through a low, broad channel across the kame delta, and Black Run would have eventually resumed its preglacial course.

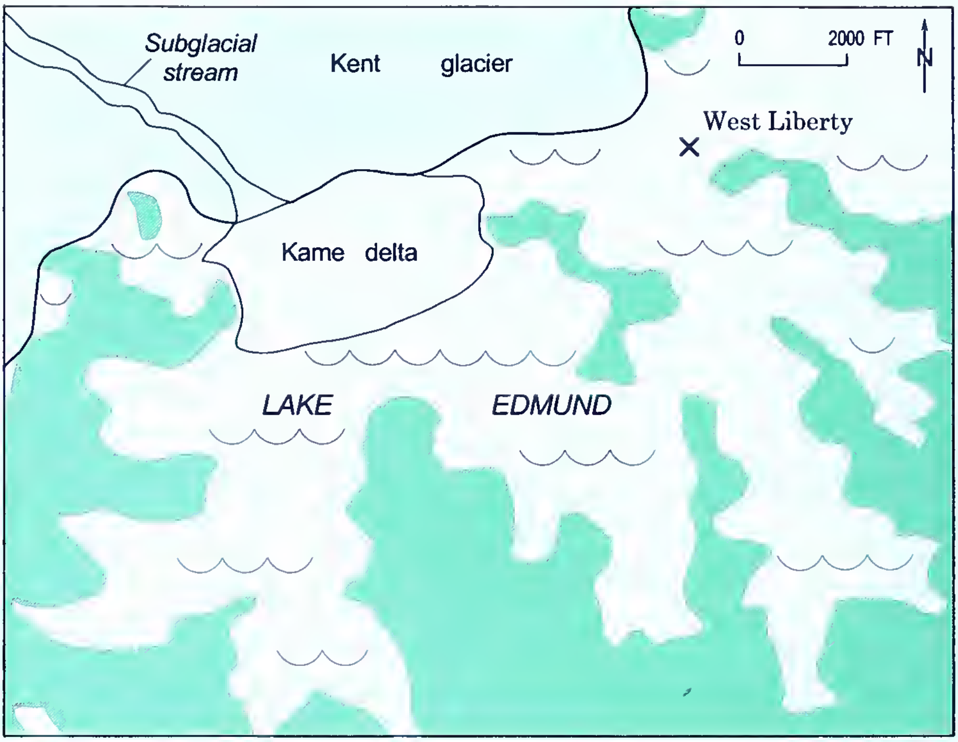

Figure 3. During the Kent glacial maximum, Lake Edmund covered much of northern Butler County, including Black Run and Hogue Run valleys. The lake level was probably about 1,310 feet. Areas that are greater than 1,300 feet in elevation today are shown in the darker color.

PRESENT DRAINAGE. This stream diversion has increased the headwaters area of Hogue Run and has resulted in its present anomalous configuration (Figure 1). Hogue Run now drains the upper part of the preglacial Black Run valley. Black Run continues to flow in the lower reach of the preglacial Black Run valley. The kame delta now forms part of the divide between Black and Hogue Runs.

Presumably, this diversion occurred during the Kent glaciation, based on its association with the Jacksville Esker. This esker has been interpreted to be of Kent age because it terminates at the Kent Till border (Shepps and others, 1959) and because its position appears to have been partly controlled by crevasses in a thin glacier (Fleeger, 1986). The Kent glacier was very thin, whereas the preceding Titusville glacier, which was responsible for most drainage diversions in the area (Fleeger, 1984), is interpreted to have been very thick (White and others, 1969). Thus, this diversion occurred about 21,000 to 22,000 years ago.

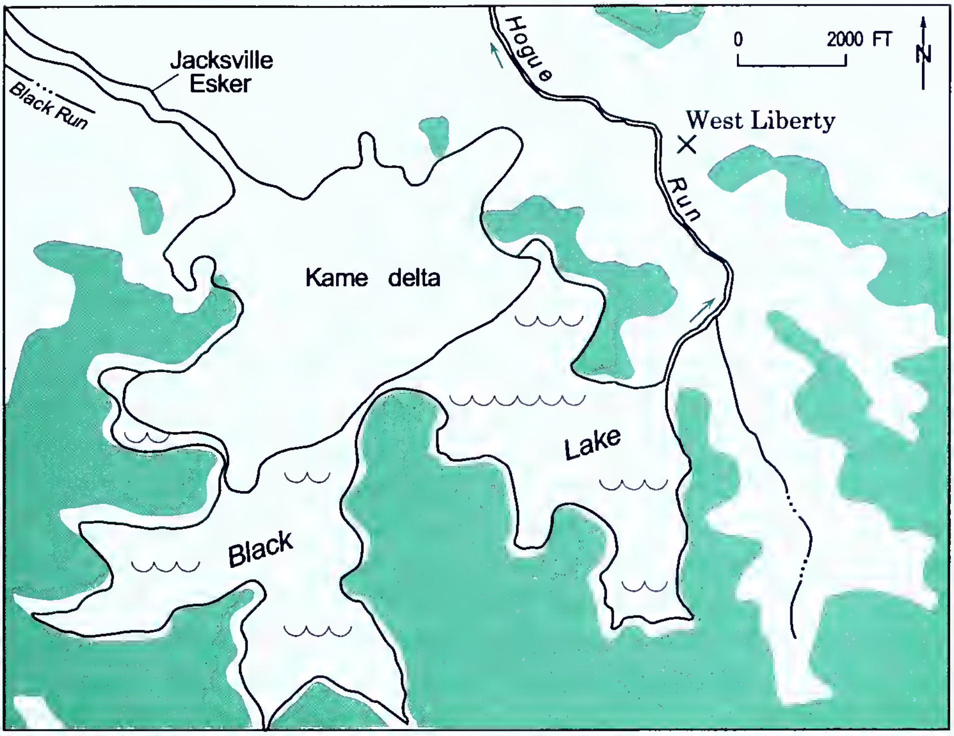

Figure 4. The level of Black Lake, initially at about 1,280 feet, was controlled by the elevation of the low point in the divide between Black and Hogue Run valleys. Areas that are greater than 1,300 feet in elevation today are shown in color.

This drainage diversion is relatively small in terms of watershed area and volume of streamflow, but it illustrates the complex interactions that can occur during continental glaciations.

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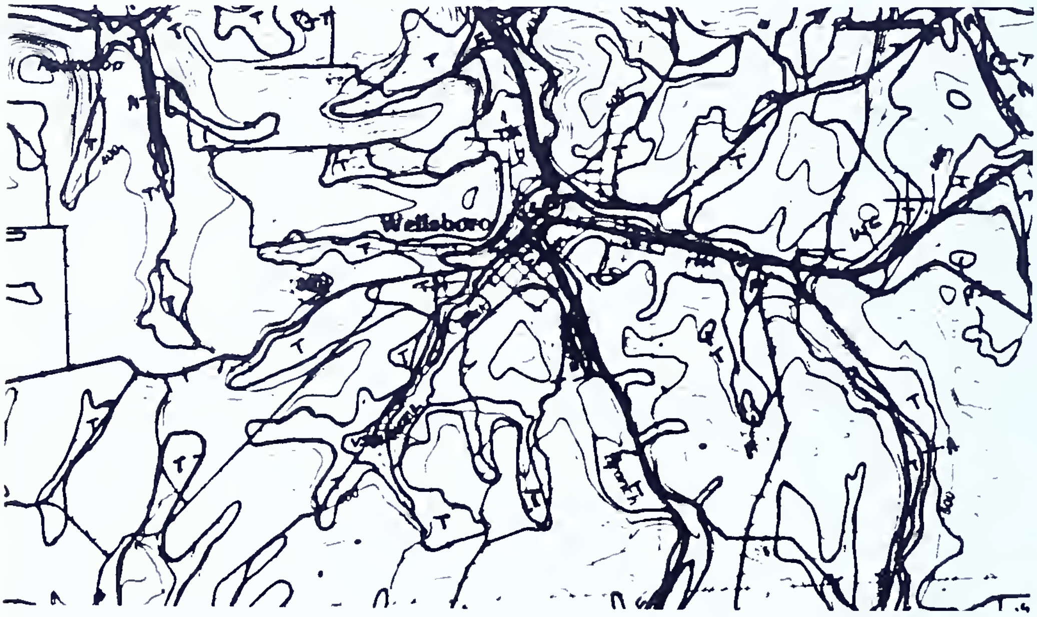
Surficial Geologic Maps of the Wellsboro and Towanda 30- by 60-Minute Quadrangles

The Pennsylvania Geological Survey has released Open-File Reports 97–02 and 97–03, **Surficial Geology of the Wellsboro and Towanda 30 x 60-Minute Quadrangles, Pennsylvania**, by William D. Sevon of the Pennsylvania Geological Survey and Duane D. Braun of Bloomsburg University.

The combined reports consist of two black-and-white photocopies of 1:100,000-scale surficial geologic maps, accompanied by a well-illustrated 25-page text in which the authors describe the 13 mapped surficial geologic units (alluvium, alluvial fans, glacial till, ice-contact stratified drift, lake sediments, colluvium, ice-contact sand and gravel, and others). The text also contains several detailed 1:24,000-scale maps of selected areas within the two 30- by 60-minute quadrangles. The trace of the Wisconsinan "terminal moraine" is indicated on the Wellsboro sheet. Some of the de-



Part of the surficial geologic map of the Wellsboro 30- by 60-minute quadrangle tailed maps show landslide scars in the lake sediments (or in the combined till and lake sediments).

Open-File Reports 97–02 and 97–03 may be purchased from Open-File Sales, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, for the prepaid combined copying and shipping costs of **$5.00, plus $0.30 state sales tax** for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*.

The report may be examined in the library of the Pennsylvania Geological Survey, Evangelical Press Building, Second Floor, 1500 North Third Street, Harrisburg, and in the Pittsburgh office of the Survey at 500 Waterfront Drive.

For further information on open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–787–6029.

Surficial Geologic Maps of the Allentown Area

Nineteen open-file reports on the surficial geology in the area of the Allentown 30- by 60-minute quadrangle are now available from the Pennsylvania Geological Survey. Three of the reports were previously announced (*Pennsylvania Geology*, v. 27, no. 3); the remaining 16 are listed below. All of the reports are by Duane D. Braun of Bloomsburg University.

OF 96–19 **Hazleton quadrangle, Carbon, Luzerne, and Schuylkill Counties**

OF 96–20 **Weatherly quadrangle, Carbon and Luzerne Counties**

OF 96–24 **Tamaqua quadrangle, Carbon and Schuylkill Counties**

OF 96–25 **Nesquehoning quadrangle, Carbon and Schuylkill Counties**

OF 96–32 **New Ringgold quadrangle, Berks, Lehigh, and Schuylkill Counties**

OF 96–33 **New Tripoli quadrangle, Berks, Carbon, Lehigh, and Schuylkill Counties**

OF 96–34 **Slatedale quadrangle, Carbon and Lehigh Counties**

OF 96–35 **Cementon quadrangle, Lehigh and Northampton Counties**

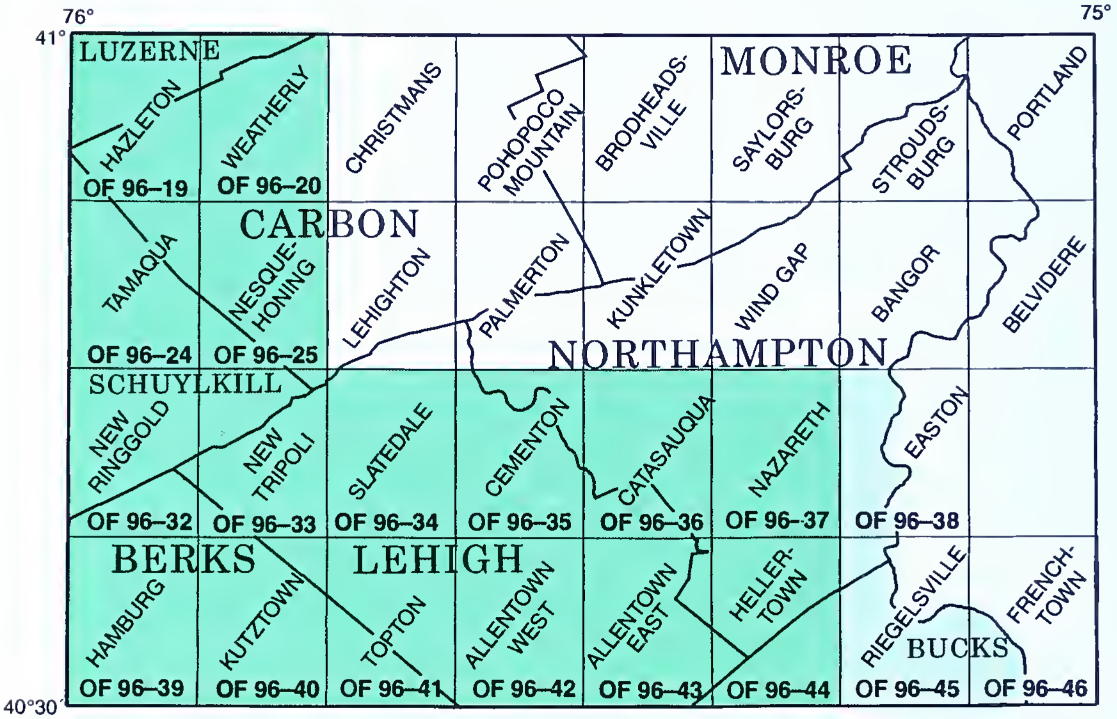
OF 96–36 **Catasauqua quadrangle, Lehigh and Northampton Counties**

OF 96–37 **Nazareth quadrangle, Northampton County**

OF 96–39 **Hamburg quadrangle, Berks County**
OF 96–40 **Kutztown quadrangle, Berks and Lehigh Counties**
OF 96–41 **Topton quadrangle, Berks and Lehigh Counties**
OF 96–42 **Allentown West quadrangle, Berks and Lehigh Counties**
OF 96–43 **Allentown East quadrangle, Lehigh, Northampton, and Bucks Counties**
OF 96–44 **Hellertown quadrangle, Lehigh, Northampton, and Bucks Counties**

Each report consists of an uncolored photocopy of a surficial geologic map hand drawn on a 7.5-minute topographic quadrangle base map (1:24,000 scale). The map is accompanied by a short (6- to 13-page) text containing detailed descriptions of the surficial geologic units, a short discussion of mapping methodology and glacial history, a table showing the relationship between mapping units and county soil series, and a sketch map of glacial borders in the area of the Allentown 30- by 60-quadrangle.

The cost of the reports is **$2.50 each, plus $0.15 sales tax** for Pennsylvania residents. For information on ordering open-file reports, please refer to the preceding announcement.



🟩 Available surficial geologic maps, announced above

🟦 Available surficial geologic maps, announced previously

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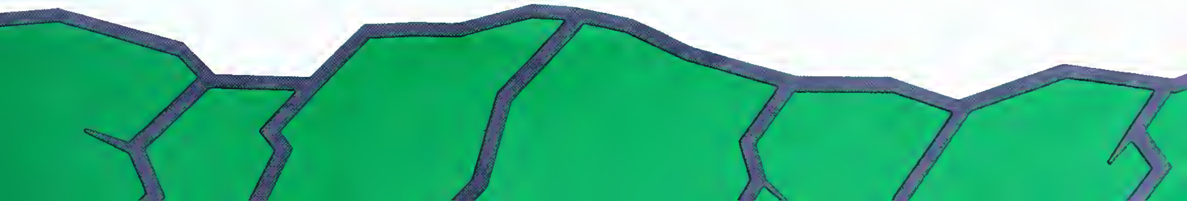

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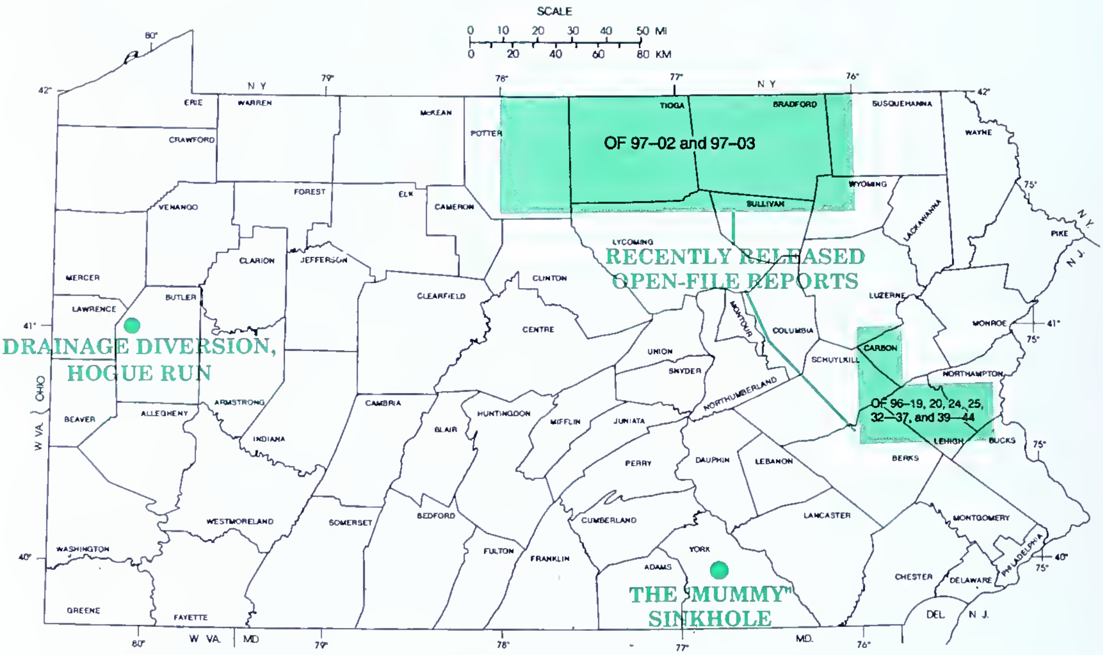

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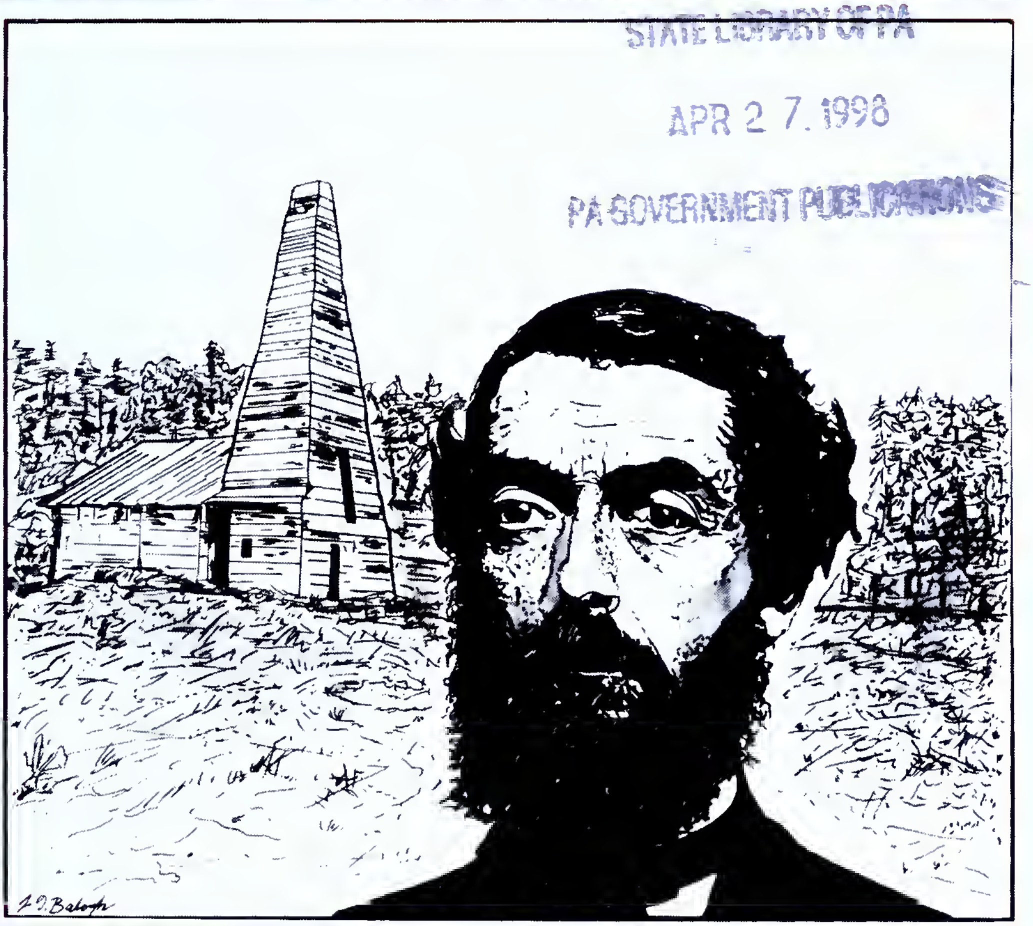

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BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
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CONTENTS

Heritages of our commonwealth 1
Why the Drake well? 2
Sur La Belle Riviere: a paean to the once and future glory of Venango County 4
The origin of oil 9
Oil Creek's riprarian wells 14
As the drill-bit churns 19
The pit and the petroleum 23
The science of drilling oil wells 27
Announcement—Survey sponsors "Geology Day" at Oil Creek State Park and releases new park guide 32

ON THE COVER

Colonel Edwin L. Drake in front of the famous Drake well near Titusville, Pa. Drawing by Lajos J. Balogh.

PENNSYLVANIA GEOLOGY

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STATE GEOLOGIST'S EDITORIAL

Heritages of Our Commonwealth

With this issue of *Pennsylvania Geology*, we begin a new activity to describe and celebrate the geologically related heritages of our commonwealth. This activity is in partnership with DCNR's Bureau of Conservation and Recreation, and with local area groups that are developing and promoting heritage resources of Pennsylvania under the Pennsylvania Heritage Park Program.

Much of the heritage of early social and economic development in Pennsylvania relates to our use of the landforms and geological resources of our state. While Pennsylvania's rugged terrain impeded and channeled transportation, the geologic resources that were contained in the underlying rocks provided the wealth for its industrialization.

One such area of early industrialization is in Venango and Crawford Counties, now the new Oil Heritage Region, where oil became the focus and fuel of development. At the Drake Well Museum and in Oil Creek State Park,[1] one can learn about the rich heritage and evolution of Pennsylvania's oil industry, which led to the present national and worldwide industry. The beauty of the Oil Heritage Region today also reflects the marvelous restorative powers of our natural forest ecosystems in a region formerly blighted by uncontrolled exploitation of a geologic resource.

Development in our commonwealth was strongly affected and fueled by the effective commercial use of the bounteous oil and natural-gas resources that occur throughout much of western Pennsylvania. The series of articles herein presented are designed to provide a geological perspective for better understanding the oil-industry heritage of Venango and Crawford Counties. The geologically related heritage of the region is so abundant that not all articles prepared for this issue could be included herein; one will appear in a future issue of *Pennsylvania Geology*. We hope these articles—descriptive, fanciful, and historical—will provide you with a better understanding of the heritage of Pennsylvania's petroleum resources.

Use of Pennsylvania's geologic resources has provided us with a common wealth of heritage and history that we should understand as we plan for future use and development of our land.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

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[1] See page 32 for a description of the "Trail of Geology" park guide recently released for Oil Creek State Park.

Why the Drake Well?

by John A. Harper
Bureau of Topographic and Geologic Survey

Most of us learned in grade school that the petroleum industry got its start in 1859 near Titusville, Pa., when an unassuming former railroad conductor named Edwin L. Drake (front cover) drilled a well to 69½ feet and struck oil. And in the ensuing years, the industry, centered around Venango County, invented and improved upon the technologies of drilling, producing, transporting, refining, and marketing crude oil and oil products, making the region one of the richest and most influential in the world. Yet a look at world history shows that, in reality, the petroleum industry was already centuries old by the time Drake arrived at his appointment with destiny.

The ancient Sumerians, Assyrians, Persians, Egyptians, and others were dealing in oil and oil products, such as asphalt, in 4,000 B.C., and the business was old then. There were various uses for oil products, such as waterproofing boats, embalming dead pharoahs, greasing chariot axles, and mortar for masonry. The Chinese had a complete oil and gas industry in 100 B.C., from drilled wells to bamboo pipelines, and even junk "supertankers," transporting oil and gas for light and heat (Figure 1). The Greeks, Romans, and Carthagenians used oil for a variety of purposes, including military ones. The Incas were using petroleum products for waterproofing, embalming, and medicine when Europeans "discovered" the New World.

In Europe during and after the Renaissance, many people were acutely aware of the history and worldwide occurrence of oil. European universities were experimenting with and teaching sophisticated organic chemistry and technology that would eventually become the backbone of the oil industry. Europeans settling in North America quickly learned from the natives; petroleum products became important to the colonies centuries before the country we call the United States was hewn from the forests, prairies, and mountains. In remote parts of North America, many people used rock oil as a cheap, if obnoxious, form of energy. Most early American citizens considered oil a nuisance: burning with a thick, foul-smelling smoke, creating fire hazards, contaminating fishing streams, and spoiling salt production (in the 1800's, most of the salt in western Pennsylvania came from evaporated salt water obtained by drilling wells). But oil was readily available in numerous seeps across the continent, and the pragmatic settlers used what was at hand. Then, just prior to 1859,

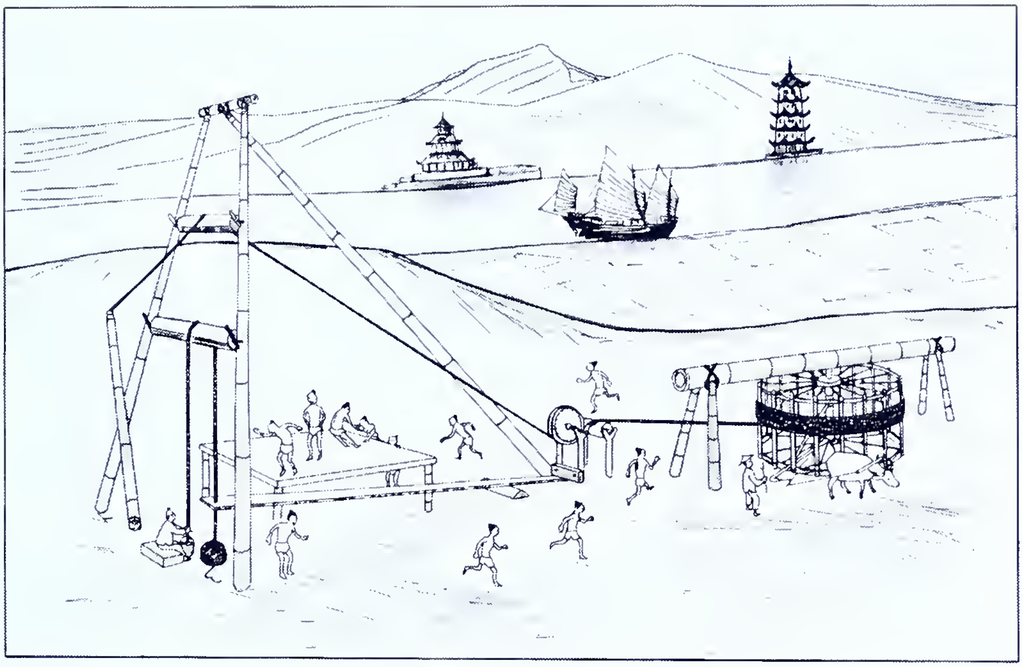

Figure 1. The Chinese had a complete petroleum industry over 2,100 years ago. Drawing by Lajos J. Balogh.

there were several deliberate attempts to drill or bore for oil in places like Germany and Canada, including the successful operations of James M. Williams in Ontario.

So, with all this history preceding it, why is the Drake well, and the man who drilled it, credited with founding the oil industry? And beyond that, why was "...one of the world's most essential industries left to grow up in the backwoods of Pennsylvania[?]" (Owen, 1975, p. 1). The answers to these questions lie in the vagaries of timing and vision. As Owen (1975, p. 1) continued, "The fact that the cumulative experience became productive at this location—and that the ancient tradition did not mature until this time (1859)—constitutes one of the great paradoxes of economic history." By 1859, the old chronicles had (as usual) been forgotten, and four factors had come together to ensure Drake's place in history.

First, the world supply of whale oil, the chief source of fuel for lighting in the "civilized world," was being rapidly depleted due to overwhaling, and the price had climbed to $100 per barrel in the United States. Oil and gas distilled from coal, the only other readily available sources of illumination other than candles, were expensive and were produced in limited quantities in America. Second, Yale professor Benjamin Silliman, probably the best-known chemist from North America, had successfully broken down crude oil through distillation into eight distinct products, each of which had its own potential value. For example, paraffin, the last distillation product, is still used for making candles and sealing wax among other things. Third, Samuel Kier, the successful Pittsburgh entrepreneur who sold crude oil for medicinal purposes, invented and promoted a method of refining crude oil to remove most of its impurities. He also invented an improved lamp burner that allowed the refined oil, or kerosene, to burn with a bright flame while emitting little or no foul odor. And fourth, through a series of circumstances, a sample of oil from the property of Brewer, Watson and Company, a lumber company on Oil Creek, came to the attention of George A. Bissell, a New York lawyer and promoter. This factor was perhaps the most important of all, because Bissell, whose excitement over the oil sample enticed him to co-found the Pennsylvania Rock Oil Company that hired Drake, had the foresight to understand the potential for commercial development of crude oil, and he set about realizing that potential.

So when August 27, 1859, rolled around, the stage had already been set, and the play was well into the final act. The promoters of Pennsylvania oil fields had better publicity than their competitors in Germany, Canada, and elsewhere, and the theater had standing room only. The curtain call would be what we now recognize as the modern petroleum industry. It could have happened anywhere oil is found. It could have involved any one of a large number of people with imagination and resources. But, in fact, it did not, and the rest is, as they say, history!

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Sur La Belle Riviere: A Paean to the Once and Future Glory of Venango County

by Kathy J. Flaherty and John A. Harper
Bureau of Topographic and Geologic Survey

AN EARLY VIEW. When French explorers first came to northwestern Pennsylvania, so impressed were they with the scenic landscape and waterways that they named the dominant stream, the Allegheny River, “La Belle Riviere” (the beautiful river). On its tortuous journey from its headwaters in Potter County, Pa., to its confluence with the Monongahela River in Pittsburgh, the Allegheny River passed through some of the most picturesque country on the new continent. In what is now Venango County, the pioneers discovered breathtaking vistas of winding streams, rolling hills, and gorges, all draped with lush vegetation. Today, three or four centuries later, much of the area appears as it did when the French first observed it.

For a time, however, Venango County and adjacent areas were not so pretty. During industrial development in the nineteenth and early twentieth centuries, the hills were denuded by overlumbering, and oily, muddy hillsides sprouting a multitude of derricks replaced the greenery (Figure 1). Jams of logs, rafts, oil barrels, and other evidence of human habitation polluted the streams, and both waterways and roads became festering sewers. But that was long ago. Now, as if by magic, nature and time have cooperated to restore the region to much of its prior scenic glory.

One might ask, How did northwestern Pennsylvania get to be so picturesque? What serendipitous conjunction of time and earth process occurred to create this scenic landscape? And how did the interactions of European settlers and the land affect the development of Venango County?

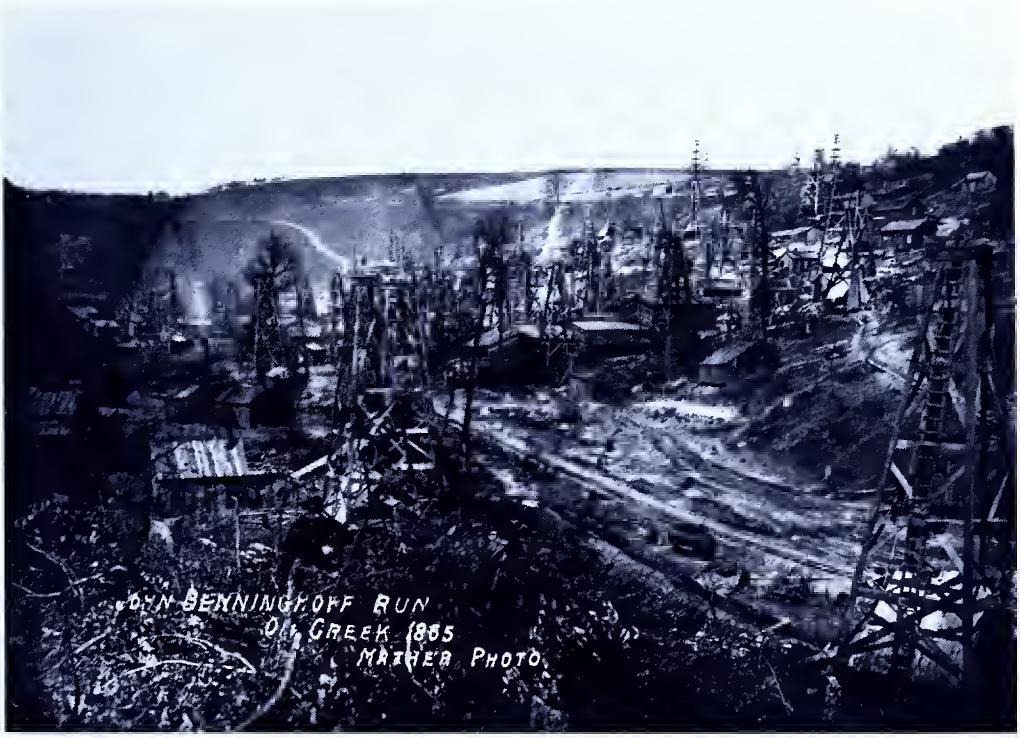

Figure 1. Mather photograph of Benninghoff Run, a tributary of Oil Creek, in 1865, showing the area to be a barren wasteland crowded by oil derricks too numerous to count. Photograph courtesy of the Drake Well Museum.

THE REGION THAT CAME IN FROM THE COLD. The answers begin in the antiquity of geologic time. Hundreds of thousands of years ago, the global climate changed drastically, and great sheets of ice, miles thick, covered the north polar regions as far south as the fortieth parallel. The Ice Age had begun. Prior to the invasion of the first glacier, the dominant waterway in Venango County was the “Middle Allegheny River,” which originated northeast of Tidioute in Warren County and followed the approximate present course of the Allegheny River through Venango County, past Oil City to Franklin. At Franklin, it turned northwest along the course of what is now French Creek and flowed across Crawford and Erie Counties into an ancestral Lake Erie basin (the Great Lakes did not yet exist). As this first of four ice sheets advanced southeastward through northwestern Pennsylvania, the ice blocked the “Middle Allegheny” and other north-flowing streams, causing lakes to form along the leading edge of the glacier. Eventually, the lakes became so deep that the water flowed over the hilltops and ridges separating the streams, reversing the direction of ancient drainage in the area. Water from the melting glacier greatly increased the natural flow of the streams, generating enough energy to scour the landscape and transport large amounts of silt, sand, and gravel formerly trapped in the ice. Eventually, the river valley widened in places, and its bed became clogged with a thick blanket of glacial debris.

As the glacier melted, the earth’s crust, which had been depressed by the weight of the ice, began to rebound. The land surface rose, and the river cut down into the surrounding bedrock, sometimes creating new channel segments. Remnants of the old riverbed remain stranded like “shelves” above present stream levels. Perhaps the best example of this is the long flat area on the south side of the Allegheny River between Franklin and Oil City where Joseph Sibley built his famous River Ridge Farm. Another example is the valley on the north side of Point Hill, across French Creek from Franklin. The valley, now occupied by the borough of Rocky Grove, formerly was the channel of the “Middle Allegheny River.” These shelflike remnants eventually became the workbenches of Venango County during the 1800’s, supporting industry, roads, railroads, and towns. By the end of the Ice Age, about 10,000 years ago, the region had deep gorges, flat river terraces, till-covered hillsides ideal for the growth of lush vegetation, and south-flowing rivers and streams.

MUD ROADS AND TREACHEROUS WATERS. The banks of the principal waterways of northwestern Pennsylvania were ideal sites for towns; therefore they were settled long before petroleum was discovered. Oil City, located at the junction of Oil Creek and the Allegheny River on land once granted to Cornplanter, Chief of the Seneca Indian Nation, had a grist mill, iron furnace, store, warehouse, hotel, and steamboat landing by the mid-1800’s. Franklin, a thriving town since the late 1700’s, boasted a rolling mill that manufactured "bar-iron" and nails, machine shops, flour mill, and foundries, and was able to accommodate the growing oil region due to its key location at the confluence of French Creek and the Allegheny River.

Heavy pine forests along the Allegheny River and its tributaries provided timber for the principal industry of lumbering. Sawmills built near the headwaters of Oil Creek, a major lumbering locality, accommodated this industry. The waterways provided convenient transportation; logs and sawed wood were lashed together and floated to downstream destinations, including some of the numerous iron furnaces found in the county.

After the discovery of petroleum in the region, small towns sprang up along many of the streams, principally as shipping sites for supplies and equipment entering, and oil leaving, the region (Figure 2). Oil shipments added considerably to the traffic on the waterways. Oil spills occurred with regularity and frequently amounted to slicks of thousands of barrels of oil coating the river and its environs. The bustling oil industry brought about undesirable changes in the characteristics of the region's roads as well, most of which paralleled the streams on flat terraces. Wet weather contributed significantly to the rapid deterioration of these roads to muddy ruts. Rocks and soil sliding down the steep hillsides, oil drip-

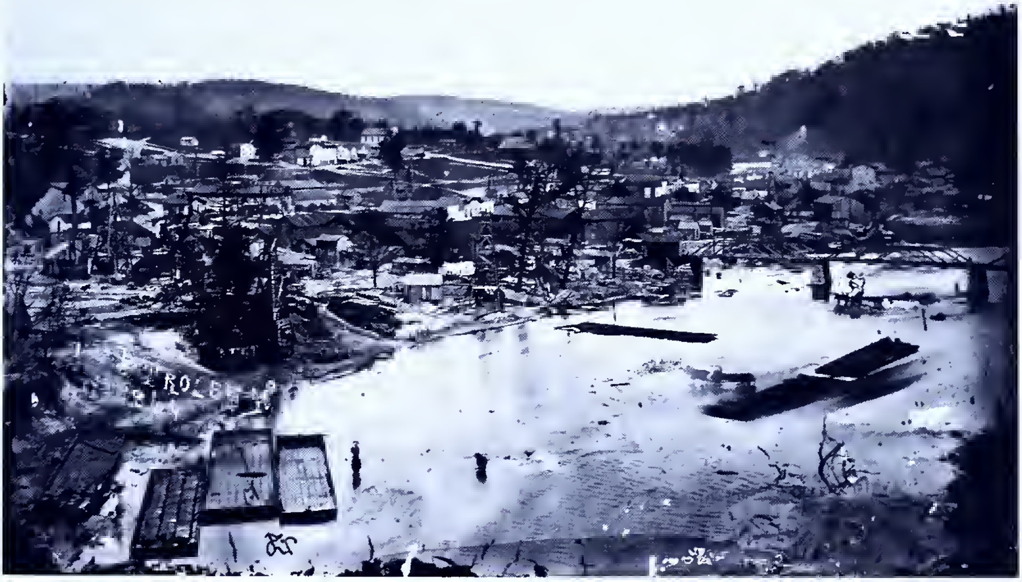

Figure 2. Mather photograph of Oil Creek at Petroleum Centre in 1864. The creek was littered with debris and probably had a scum of oil on the surface. Photograph courtesy of the Drake Well Museum.

ping from leaking barrels being hauled to market, and other debris typical of human habitation, such as the occasional horse carcass, added to the slop.

Railroads brought relief and order to the people and freight traffic moving through the region. Raw materials such as lumber, oil, and pig iron could now be transported directly to major industrial and shipping centers such as Pittsburgh, Philadelphia, and Cleveland. Like the roads, the early railroads skirted the edges of the river on the shelflike remnants of the old riverbed; they were also located on new flats blasted out of the mountains. Transportation of oil via the mid-1800's innovation of railroad tank cars and pipelines led to significant improvements in the quality of the regional waterways and roads as frequent large oil spills became a thing of the past.

OH, BEAUTIFUL (AND FUNCTIONAL) FOR SPACIOUS SKIES. It has taken many years, but Venango County and the surrounding oil country have made a dramatic comeback from the days when derricks were as thick as trees on the otherwise barren, oil-soaked hillsides. The creeks and the river now are major recreational playgrounds for fishing, canoeing, kayaking, swimming, or just lolling back on a stone beach and basking in the summer sun (Figure 3). The tree-covered mountains and the shrub-lined stream banks are replete with wildflowers, waterfowl, and game. Oil Creek valley is now a state park catering to visitors' historical and recreational pursuits. Small, but scenic waterfalls, once servicing the iron industry, dot the countryside (Figure 4). Yet as idyllic as this sounds, industry has not vanished. Venango County oil wells still produce about 700,000 barrels of oil per year; drilling and production of natural gas, oil refining, and chemical manufacturing play significant roles; bituminous coal and limestone are mined in the southern part of

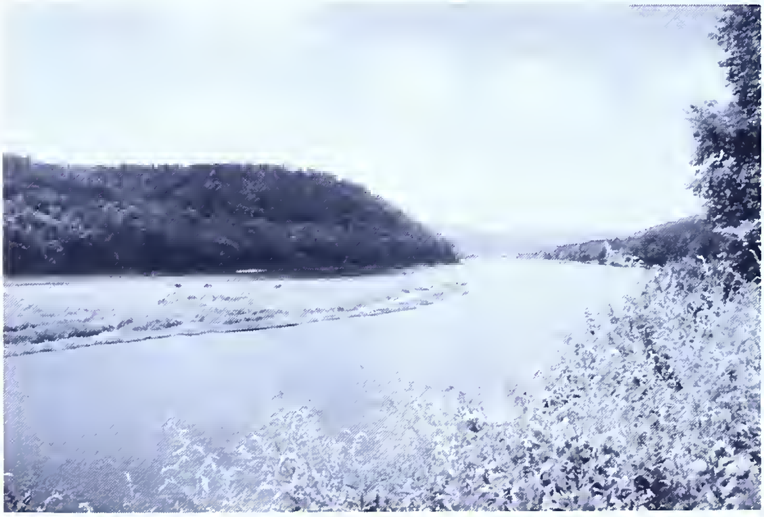

Figure 3. The Allegheny River south of Franklin. The hills are once again forested, and wildflowers thrive on the riverbanks.

Figure 4. Freedom Falls on Shull Run in Rockland Township. In 1832, Andrew McCaslin constructed the Rockland iron furnace about 100 yards downstream from this site and built a flume to transport water from the elevated part of the creek to the furnace's waterwheel.

the county, gravel in the western part, and sandstone in the eastern part; and that old mainstay, lumbering, once again provides many jobs. Tourism related to the oil heritage and recreation has become very important to the local economy.

Venango County is proof that the once glorious landscape that early settlers found in northwestern Pennsylvania can return and coexist with normal human endeavors. All it takes is an understanding of the importance of the land to the future of humanity, that and the one commodity geologists understand only too well—time.

The Origin of Oil

by Christopher D. Laughrey
Bureau of Topographic and Geologic Survey

The historic Drake well near Titusville is the best-known landmark of Pennsylvania's Oil Heritage Region. After touring the exhibits at the Drake Well Museum, tourists can stop by the gift shop and purchase mementos of their visit, including their very own sample of Pennsylvania "black gold" for only 94 cents (Figure 1). This is quite a bargain. Crude oil is one of the most remarkable substances found on our planet. Providing almost 40 percent of the world's energy, it powers our automobiles, warms and cools many of our homes, fuels and lubricates our factories, generates much of our electricity, and provides the raw materials for thousands of essential products ranging from synthetic fabrics and plastics to medicines. Thanks to its natural lubricating qualities, refined Pennsylvania Grade crude oil provides some of the best motor oil available in this country (Figure 2). That little 94-cent vial of Pennsylvania Grade crude also contains some marvelous chemicals that have helped scientists to understand some of the history of life on our planet.

WHAT IS IT? In 1859, promoters attempting to raise money to drill the Drake well collected a sample of oil from a natural seep near Titusville and gave it to Dr. Benjamin Silliman at Yale University to determine its value. Silliman accomplished his task by placing the oil in a distillation flask and boiling off eight separate fractions. He described each fraction in detail and concluded that the Venango County crude could yield an illuminating oil that would be superior to most of the available oils of the time (mostly whale oils). Silliman's analyses ensured the financing of the Drake well. Distillation is the principal method employed today for separating crude oil into its multitude of useful products.

Distillation separates crude oil into compound groups of different sizes. Chemists recognize different types of molecules in oil by their structure. The hydrocarbon molecules contain only carbon and hydrogen atoms; the carbon atoms may be arranged in straight chains, branched chains, rings, or in combinations of these. Nonhydrocarbons in the crude are composed mainly of carbon and hydrogen too, but also contain one or more of the elements nitrogen, sulfur, or oxygen, and trace amounts of metallic elements, such as vanadium and nickel. Approximately 500 different compounds are known to occur in crude oil; about one third of these are nonhydrocarbons (Brownlow, 1979).

Figure 1. Derrick-shaped bottles of Pennsylvania Grade crude oil such as this once were used by the City of Oil City and the Oil City Area Chamber of Commerce as inexpensive mementos of the area. They are now rare. Visitors to the Drake Well Museum can still obtain a small amount of oil, but in a simpler vial. Photograph courtesy of Oil Heritage Region, Inc.

Figure 2. Many brand-name lubricants still emphasize their origin as Pennsylvania Grade crude oil. Photograph courtesy of Oil Heritage Region, Inc.

IDEAS ON ORIGIN FROM ANCIENT TIMES TO MODERN. Many years of scientific research on the occurrence and composition of oil have provided us with a clear, consistent, and generally accepted concept of how crude oil forms in the earth's crust. It was not always so, however, and some dispute about the origin of oil continues today. In general, hypotheses of origin can be separated into two camps: inorganic and organic.

One of the earliest inorganic hypotheses originated with the Arabic peoples, who, in about 850 A.D., suggested that water and air combined with fire produced sulfur and mercury. The sulfur and mercury then combined with "earth" and at great subterranean temperatures yielded "naft" (naphtha) and "qir" (asphalt).

Two celebrated nineteenth-century scientists, Gay-Lussac and Humboldt, proposed that oil formed as a result of impregnation of marine sediments by subaqueous hot springs of volcanic origin. Another nineteenth-century idea suggested that oil formed by the combination of hot alkalis with carbon dioxide deep in the earth's interior. The famous Russian chemist Dmitri Mendeleef argued that percolating water encountered iron carbide deep in the earth, generating hydrocarbons. Other workers, noting that methane occurs in trace amounts in volcanic gases and in fluid inclusions in igneous rocks, assumed that it was sweated out of the earth's interior throughout geologic time, rose in the crust, changed into heavier hydrocarbons, and finally accumulated into the petroleum deposits we exploit today.

Hypotheses suggesting an organic origin for oil are also quite old. Oil and coal were linked by some naturalists as early as the sixteenth century. Chemists discovered that oil could be distilled from coal in the laboratory and postulated that this occurred in nature as well. Geologists working in Pennsylvania had problems with this idea, however, because the primary oil-producing strata lacked associated coals, and oils produced in Venango County were chemically different from oils derived from the distillation of coal. A great many mid-nineteenth-century workers, including then Pennsylvania State Geologist J. P. Lesley, advocated that oil was derived from terrestrial vegetation washed into the sea and deposited with the sandstones containing the petroleum. Problems with this idea include the fact that some oil is produced from rocks containing only marine fossils, and the observation that the high temperatures needed to convert wood into liquid organic matter are not geologically reasonable. Lesley later expanded his ideas to include marine plants and animals as a source of oil (Hedberg, 1969). This train of thought became popular in the late 1800's and early 1900's and led to the view that oil represents an accumulation of hydrocarbons that originally were produced by living organisms.

IT CAME FROM OUTER SPACE. The occurrence of hydrocarbons in meteorites has been well known to scientists since the mid-1800's. In the early 1930's, investigations revealed that methane is a major component of the large outer planets Jupiter, Saturn, Uranus, and Neptune. Because scientists believed that all the planets in our solar system were closely related in origin, some researchers concluded that the raw materials for hydrocarbons must have been present in the substances from which the primordial earth accreted 4.6 billion years ago. By the 1950's, such reasoning led astronomer Fred Hoyle to argue that the deep earth must contain vast untapped reserves of oil just awaiting our technological ability to find and exploit them (Pratt, 1956). This view is still held by a small group of scientists (see review by Gold, 1993).

THE MODERN VIEW. A great body of scientific evidence suggests that oil was formed in the geologic past from a combination of hydrocarbons synthesized by living organisms plus those formed from thermal alteration of organic matter in sedimentary rocks (Hunt, 1996, p. 109). About 10 to 20 percent of the oil in the earth's crust forms via the former mechanism, while 80 to 90 percent forms via the latter. Marine plankton are the major players in both pathways of oil formation.

Several lines of evidence support this contemporary view of the origin of petroleum: (1) oil is rarely found in rocks that formed before life developed on the earth; (2) oil contains compounds derived from the pigments of living organisms; (3) the distributions of carbon isotopes in oil is similar to those in organic matter; (4) hydrocarbon compounds found in oil affect polarized light the same way that hydrocarbons and other compounds synthesized by living organisms affect polarized light; and (5) the structures of many oil compounds are similar to those of fats and waxes found in living organisms and, therefore, could be formed from them (Krauskopf and Bird, 1995).

SOURCE ROCKS AND OIL GENERATION. So, how do we go from living organisms to Pennsylvania Grade crude oil? When organisms die, bacteria attack their remains. These bacteria require oxygen, and if oxygen is plentiful, destruction of the organic remains is complete. Abundant remains of marine plankton, however, sometime accumulate along with mud in stagnant underwater environments. The aerobic bacteria use up any dissolved oxygen very quickly. Anaerobic bacteria, which obtain their oxygen from dissolved sulfur compounds in the pore waters of the mud, then take over. These bacteria consume most of the easily decomposable compounds in the organic matter, such as proteins and carbohydrates. As the muds continue to be buried, further physical and low-temperature chemical reactions transform the chemical structure of much of the organic matter. As the temperatures increase with even deeper burial, the transformed organic debris decomposes to form crude oil. The muds compact and become shale. Petroleum migrates from the shale and travels through more porous and permeable strata until it encounters a trap.

A FINITE RESOURCE. Modern ideas about the origin of oil are based on a long history of scientific investigation. Some perceptive geologists intuitively reached the same conclusions over 100 years ago. For example, Henry D. Rogers, the first State Geologist of Pennsylvania, thought that Devonian black shales were the source of the oil found in the sandstones of the Oil Heritage Region, and he suggested that "...the greater portion of the oil and gas is derived from the marine [fossil organic matter in the] carbonaceous shales..." (Rogers, 1863). So why the appeal of so many other, sometimes fantastic, hypotheses about the origin of oil? Some historians note that the inorganic hypotheses were based on laboratory experiments by chemists and, therefore, offered both scientific validity and the reassurance of an inexhaustible supply of oil. An inexhaustible supply was implied in the cosmic hypotheses too. The organic theory, on the other hand, infers that a limited quantity of oil is available to us.

Forecasters predict that crude-oil production will be able to supply increasing demand until peak world production is reached in about the year 2020 (Edwards, 1997). Conventional crude-oil production should terminate in the United States in the year 2090, and world production should be near exhaustion by the year 2100 (Edwards, 1997). Colonel Drake launched a remarkable industrial era in 1859, but the end of that era is clearly in sight. The recognition of the organic origin of oil is an acknowledgment of the finiteness of the resource upon which we depend for the quality of our lives. Let us hope this recognition compels us to use what remains of this resource prudently and to properly manage the challenges and changes ahead.

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Oil Creek's Riparian Wells

by Samuel T. Pees
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America's pioneer oil well drilled by Colonel Edwin L. Drake in 1859 was a *riparian* well. The word "riparian" strictly means "on the bank of a stream," but in the broad sense it seems reasonable to include the adjacent flats that are subject to frequent flooding, low islands, gravel bars, and the streambed itself. Many of the wells that were drilled after Drake's well in the first decade of oil were also riparian. Drake drilled in the flats about 150 feet from the east bank of Oil Creek (Figure 1). The site was on an artificial island created by a race for the Brewer and Watson Company lumber mill and the course of Oil Creek. When the creek was in spate, the waters would flood the flats. Now, the site of the Drake well, consisting of a replica of the engine house and derrick, is protected by an earthen dike built by the American Petroleum Institute in 1931.

After Drake struck oil on August 27, 1859, at a total depth of 69½ feet, would-be oilmen crowded the valley and commenced a drilling spree that saw wells fill the flats, the islands, and finally, here and there, in the creek itself. Some were drilled a short distance up the cascading tributaries, often directly in the narrow runs themselves. The same drilling scheme took place along the banks of the Allegheny River and on its islands. Watercourses were hugged during the very first years by most operators; bottomlands and stream banks were favored localities, a notion unwittingly set by Drake. His selected site was on a well-known oil seep, but it also happened to be on bottomland and near the creek bank. It was a while before the first oilmen left the creek valley and tested the plateaus in earnest. Even on the higher land, the first operators preferred to locate their wildcat wells on drainage courses. Another possible reason for early "creekology" may have been the need for water for the boilers.

The incentive to drill closely spaced wells in the highly competitive days of the first boom in Oil Creek valley was the phenomenal production of flowing wells that were brought in at rates of 1,000 to 4,000 barrels of oil per day from depths of only 450 to 550 feet. Names of the giant wells quickly found their place in history books: Empire, Buckeye, Noble, Fountain, Sherman, Phillips-2, Coquette, and many more. These wells tapped the Venango Third sand, which contained the great volumes of oil and high pressures that caused the gushers. Flowing riparian wells at Pioneer, Funkville, Petroleum Centre, and Tarr Farm required enormous efforts to contain, but they made enormous profits too. Other producing sands in this belt were the Venango First and Second, the latter often prevailing after the Third sand was lost.

Efforts to get as close to the giants as possible led to drilling in the creek or behind barricades that diverted the stream waters. Seeps were favored localities. One famous seep was in the middle of Oil Creek at the Hamilton McClintock farm below Rouseville. Ham had collected oil at his seep via baffles since the early 1800's. He made up to 20 or 30 barrels in a season. Covetous eyes eventually caused a well to be drilled offshore at that seep site (Fig-

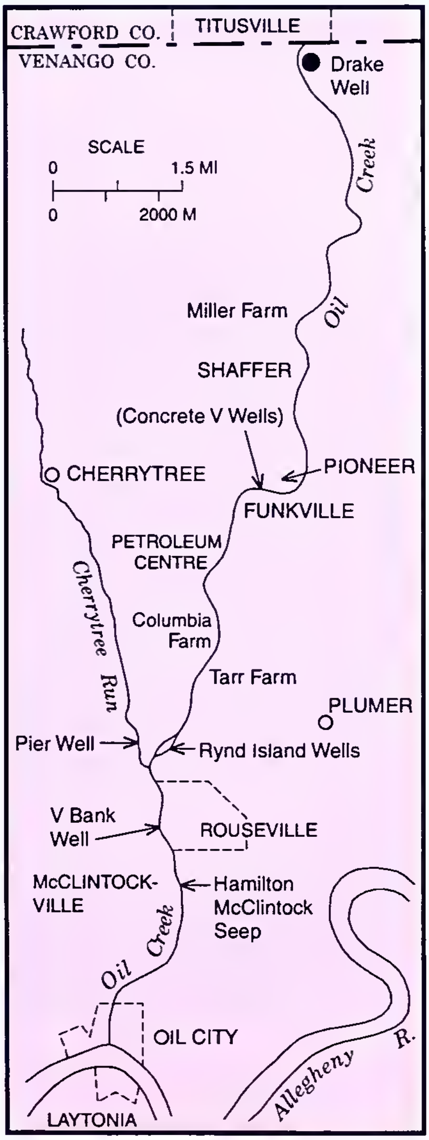

Figure 1. Map of the stretch of Oil Creek from Titusville to Oil City, about 16 miles, taken in part from Beers (1865). This was America's first oil belt, beginning August 27, 1859, with the completion of the Drake well. Gathering of oil from local seeps occurred long before then. The McClintock oil seep, riparian wells, and place names (many now ghost towns) are shown. Modified from Pees (1996, Figure 3).

ure 2). Afterwards, not much was said about it. William Phillips remembered rainbow colors at a spot in the creek at Tarr Farm. He leased a narrow strip of land along the east bank and drilled the Phillips No. 2 well in 1861. It came in for 4,000 barrels of oil per day and required a virtual army to dig pits to hold the flow; oil from the well shortly overwhelmed the containers anyway and flowed copiously into Oil Creek.

Some early riparian wells in the late 1800's, also during World War I and through the 1930's, were encased by fieldstone and timber foundations that held the pumping apparatus and wooden separator tank aloft. Some of these have survived many floods and "ice-outs" (complete jamming of the creek by ice floes), but production ceased long ago. Rynd Island wells are examples of these early wells (Figure 1).

Eager to "make land" in the shallow creek next to the flats where good production had been proven, operators built concrete or wooden V-shaped barriers with the V pointing upstream. They drilled behind the V barricade. Some of these constructions are still there, on the creek banks or at the tips of the islands that they created over time (Figures 3 and 4).

Another way to get "into the creek" was to build a pier that would jut out from the bank. One of these, on a tributary of Oil Creek, still bears a well capable of producing from the Second sand (Figure 5).

Riparian wells ruined the chances for secondary recovery in a number of places in Oil Creek valley. Left to corrode, some of the wells were

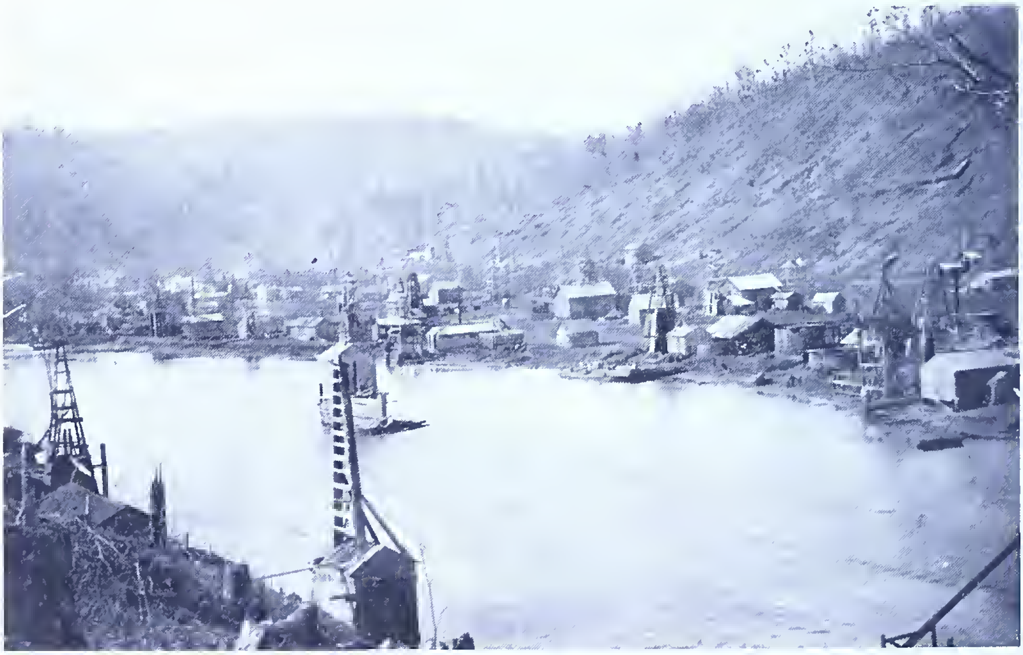

Figure 2. A well believed to be in the locality of the Hamilton McClintock seep in the middle of Oil Creek. The V has snagged some driftwood. Photograph courtesy of the Drake Well Museum.

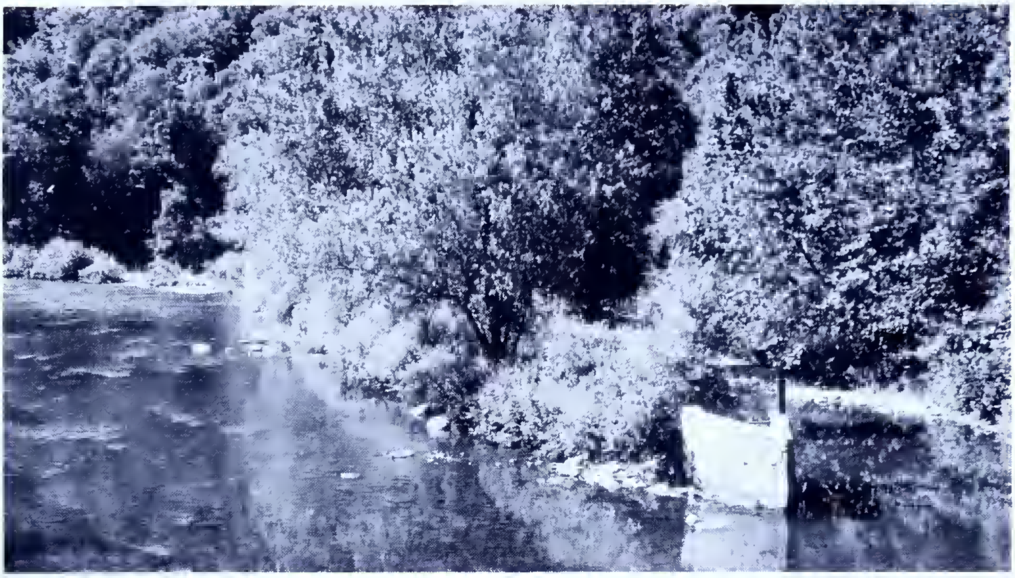

Figure 3. A concrete V pointing upstream at Pioneer. This barricade has been shifted by floods and ice-outs. A well was drilled behind the V and originally was protected by it. The island was created by the reduction of flow velocity behind the V.

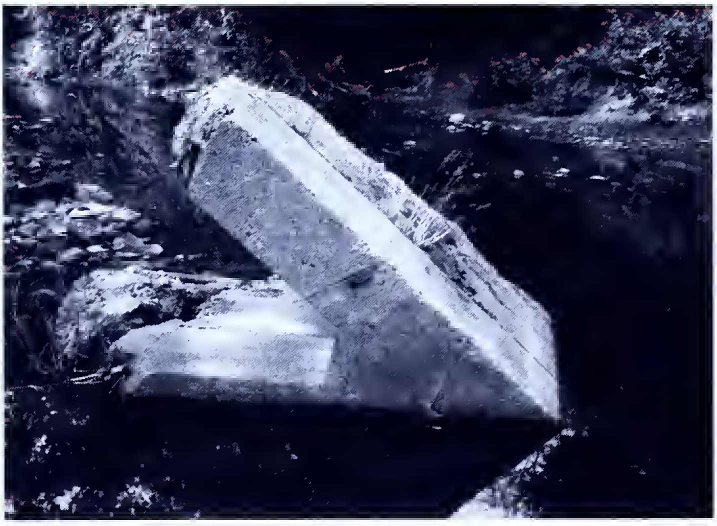

Figure 4. An overturned concrete V probably dislodged by ice flows in the Pioneer area. The well is "lost" in the creek.

eventually invaded by fresh water, causing massive accidental flooding of the reservoir. Unfortunately, the Third sand was usually the victim.

Stories of riparian wells in the Pennsylvania oil belt are legion. The most interesting facet of this method of production is that traces of the wells still exist. From what the writer has seen of Oil Creek, a boat could grind over one or two of the wells. Another early well casing, which juts out of the water, could upset an unwary canoeist. Some wells are on gravel bars that are inundated during high water (Figure 6).

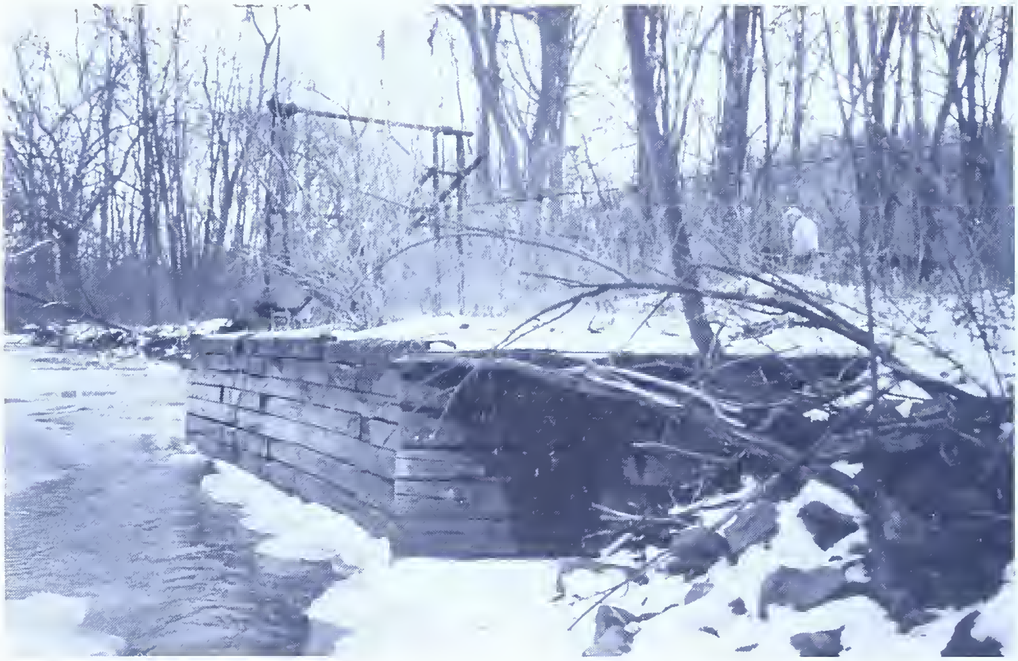

Figure 5. A pier jutting into Cherrytree Run, a tributary of Oil Creek. Note the Oklahoma-type pumping jack. This pier well can produce from the Venango Second sand. Photograph by Ellsworth "Pete" Sparks.

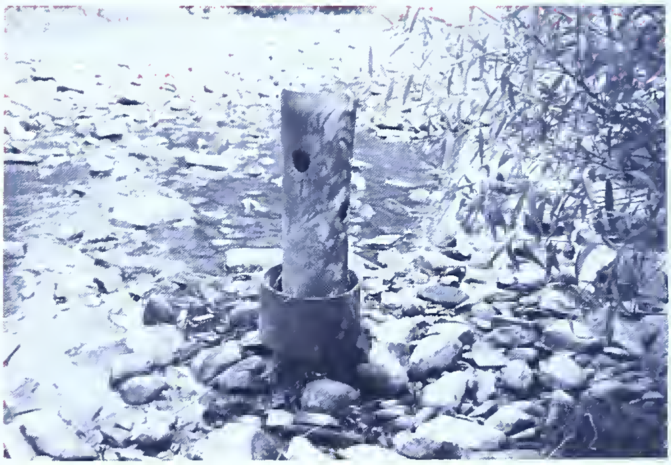

Figure 6. An abandoned gravel-and-cobble-bar well in Oil Creek at Pioneer. This bar is often under water.

It is no wonder that oilmen eventually ventured offshore into the world's oceans and its larger lakes. A precedent had already been set in the waters of Oil Creek in the 1860's and later.

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As the Drill-Bit Churns

by Kathy J. Flaherty
Bureau of Topographic and Geologic Survey

Many a fortune-seeker abandoned home, family, and job to try his hand at drilling in hopes of striking it rich with a prolific oil well. Fortunes were made; many, also, were lost. As if the process of poking holes in the planet in hopes of puncturing a pocket of crude were not risky enough, the roller-coaster economics of the early oil industry could drive even a successful oil prospector to abandon the fields for something more secure.

Will Shaw (Figure 1) is a fictitious geologist. He was a recent college graduate, eager to use his education to prove himself and win the hand of his beloved. Will's quest was twofold. First, he wanted to find oil and get rich. More important to us was his second goal: to find oil by using geological principles that were still very much in the formative stage as far as subsurface exploration was concerned. While Will's contemporaries in the oil fields were ready to embrace the current drilling fads, Will was convinced that application of basic geological principles would guide his exploration endeavors successfully, and he set out to prove it!

* * *

My dearest Elsbeth, *April 4, 1868*

I am hopeful that this greeting finds you in good health and good spirits. I have arrived in Pleasantville, Pennsylvania, having had an uneventful journey. Accommodations are scarce, and I regard myself as fortunate to have found a bed in a clean and dry boarding house near the center of the drilling activity. The room is shared by several gentlemen who are also seeking their fortunes in the oil patch, but as it is away from the mud and hustle and bustle of the oil-field workings, it is quite satisfactory.

From the window in my community room, I glance over the countryside with amazement. The hills are barren of all but mud and oil-well workings; trees have been replaced by wooden derrick towers and shrubs have changed into barrels to collect and store oil. Muddy ruts make up the road passages, and already I find that heavy boots and thick woolen socks are a necessity.

It is my observation that there is no requirement of a comprehension of geology to conduct drilling enterprises. Since my arrival, I have become acquainted with other occupants of the boarding house. The prior pursuits of these gentlemen who are now in search of the financial rewards of successful petroleum endeavors are as varied as

Figure 1. Fictitious geologist Will Shaw stands among the derricks in the oil patch. Drawing by Lajos J. Balogh.

they could be. Among their numbers are a former county treasurer, railroad executive, blacksmith, several farmers, merchants, jeweler, and even a piano tuner, all hopeful for a big strike. I have not yet met another geologist, and when an inquiry is made of my profession, I am too often treated as a curiosity. I do believe they regard the concept of using science to locate a likely supply of petroleum as laughable.

Conversing with some gentlemen in the dry-goods store, I have learned that the task of leasing property to drill for oil consists of whatever agreement can be made between the landowner and the leasee. Such agreements seem to be inconsistent and depend in part on the sophistication of the landowner. Some are clever enough to demand 3/4 of the revenue of the well, although the more common arrangement is that the landowner receives 1/8 of the well's production. A few stories are circulating about landowners who demanded their payment in oil, already in barrels, instead of in cash dollars. The demand for barrels is so extreme, and the price so dear, that to provide them costs more than the value of the oil itself! I have been warned by these men to beware of leases offered by enterprising leasing agents who have taken oil leases from the landowners. Frequently, they have promised the landowner 1/8, or even as little as 1/10, of the royalty and keep 1/3 to 1/2 plus a large bonus for themselves, merely for providing the lease to a driller! I promise you, dear Elsbeth, that I will not become engaged in such a deal as will be self-defeating for want of economics, for then I shall neither amass my fortune nor receive the blessings of your father to take your hand, and happiness will continue to elude me. Hopeful that when next I correspond I will be able to give you a substantial report of my progress, I am

Ever your humble servant,
Will Shaw

* * *

My dearest Elsbeth, *May 11, 1868*

As always, my fondest thoughts are with you. I thank you most sincerely for your correspondence. I relish news of home and your activities there.

I have at last secured a lease upon which to begin putting down a well. It is on a farm of 23 acres fairly near here. Although the farm had been leased in 1866, a well was never completed there. A group of local farmers had pooled their funds and started a well, only to run into troubles with tools stuck in the hole and other costs that they did not anticipate. Their life's savings poured into the hole and thereby depleted, they were forced to abandon the effort, never reaching near the oil sands. In deciding where to sign a lease, I was much influenced by the reports of the quality of the 5th sand, which drillers nearby have described as a very pebbly rock unit. I believe that a rock of these characteristics is most desirable, as it is likely to readily store and surrender petroleum upon penetration by the drill. A drilling crew of 6 able men has been secured, and they will work in 2 shifts of 3 men each. The rig and hardware are nearly fully assembled, and I believe we will be in a position to begin drilling on the morrow.

Our costs thus far total $4,290 for the supplies, hardware and some crew wages. I am making a careful accounting, as I have been entrusted with the funds of several investors who are certain to hold me responsible. Wages and the 10-horse-power engine are the most costly items: pipe is $6 per foot, and coal to power the engine is $0.50 per barrel. If we experience no unforeseen obstacles, I expect our enterprise will not exceed $5,000.

Once drilling has commenced, I will spend the most amount of time possible at the well site, stopping only for rest and nourishment in town. As drillers are apt to carelessly race through the rocks with as much speed as is mechanically possible, it will be necessary that I temper their haste. I must convince them that it is essential to cease drilling to take frequent, careful depth measurements, and to collect the drill cuttings for my scientific analysis. We will be using a diamond drill to penetrate the rock. It has the effect of cutting cylinders of solid material from the earth. These cylinders are then brought to the surface by means of clamps lowered into the hole. I have seen examples of rocks withdrawn by this method, and find them to be ideal for geological study. The rocks remain somewhat intact, and fissures, changing characteristics, and bedding planes can be examined.

Please forward my most sincere regards to your kin. I trust that your Father will consider my progress in this endeavor a good faith effort to fulfill the promises I made in anticipation of our betrothal. Eagerly anticipating your joyous receipt of this news, I am

Your humble oil-field servant,
Will Shaw

* * *

My dearest sweet Elsbeth, *September 29, 1868*

Your kind words and reassurances of a more pleasant encounter when next I meet your Father have sustained me through the most tedious days at the well, when we only progressed 10 feet per day. I can only hope that your Father will find a new respect for my work with my success in bringing in a productive well of both financial and geological merit.

We have completed the drilling of our first well on this farm and have realized a profitable well from which we pump nearly 200 barrels per day, very consistently. The production is from the 5th sand, which was coarse and pebbly as I had predicted based on geological characteristics. It was first encountered at 820 feet below the mouth of the well, and 14 feet into the coarse sand, we reached the oil pocket concealed therein. I am somewhat vindicated and have been approached by no less than 17 companies to assist them in determining locations based on geology for their future wells! Please be assured, sweet Elsbeth, that I will do nothing that will inhibit our financial development or delay our joyous reunion. While I am relishing this new-found respect in the oil community, the success is a coup for the science of geology in so practical an application. Use of geological science is a far cry from use of a witch-hazel divining rod, or recitation of incantations, or any of the many other whimsical approaches that have been so frequently employed here.

I negotiated a premium price of $4.25 per barrel for the sale of our oil, as the market here is currently very strong. We have, after only a few weeks of production, paid for the drilling of this first well and have paid a small dividend to our investors. We have begun the construction of another drilling site and will commence to drill within a fortnight.

I am confident that the coarse nature of the 5th sand, so prolific here, continues on the far side of this lease and beyond, as it is found also in wells drilled a few miles from here in the same direction. A belt such as this can only be accurately followed through careful documentation of the rocks encountered as the drill proceeds. It is critical that records be kept in a methodical fashion, with all details noted objectively. I truly believe that only through the most thorough and painstaking diary of every measurable characteristic will we gain an understanding of the attributes that constitute oil-producing rock reservoirs.

Our second well should be completed by the Winter Solstice, and I am planning to return to you in time to celebrate the Holidays. I will once again request an audience with your Father to request your hand in marriage. It is my only desire to bring you to oil country as my wife when I return to drill a new prospect in the Spring. With blissful anticipation of our Holiday encounter, I remain

Your most humble oil-field servant,

Will Shaw

Our geological hero proved that a successful prospect could be defined and drilled based on science. His achievement won over his sweetheart's father, and so Will and Elsbeth were married on the feast of St. Valentine in 1869. They lived happily in the town of Franklin for several years, where they raised a family of two sons and seven daughters. Will continued to drill profitable wells in his new-found career as a petroleum geologist. Having amassed a fortune in Venango County oil, Will and Elsbeth turned the business over to their children in 1904, and they pursued philanthropic interests.

The Pit and the Petroleum[1]

by John A. Harper
Bureau of Topographic and Geologic Survey

OIL, OIL EVERYWHERE . . . BUT WHERE? When the modern oil industry was still in its infancy in the 1860's, many of those involved had no idea what they were doing beyond putting a hole in the ground so that the oil could flow out. And put holes in the ground is what they did—thousands of them, some so close together you could spit between drilling rigs.

Wells were drilled in creek valleys, on hilltops, and anywhere in between where there was a patch of unused ground. One operator would swear on the necessity to drill along a creek bed because he was convinced the oil flowed in a cavern or fissure below the creek. A competitor would announce that drilling on uplands made more sense because the newly devised anticlinal theory claimed oil accumulated at the tops of folded rocks, typically associated with mountains. Yet another competitor would hasten to say that both the preceding ideas were hogwash. He knew for certain that the oil accumulated in straight-line "belts" or "trends" that ran across country without regard to the landscape. It would be another 10 to 15 years before John F. Carll began working for the Second Geological Survey of Pennsylvania, using the Survey as a publishing outlet for his pioneering concepts about subsurface geology and petroleum technology. Not that it would have mattered—Carll's ideas were virtually ignored until the early 1900's because they did not include a single unifying theory of where to find oil (Harper, 1990). This was not Carll's fault, however, because time and experience have shown that there is no such theory. Oil and gas are found in a wide variety of geologic settings.

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[1] With apologies to Edgar Allan Poe.

In the 1860's, most of the oilmen in Venango County knew that oil was found in rock; they just did not know how the oil got there, or why it came out when they drilled into the rock. Many thought the oil occupied large holes and fractures, or even formed underground lakes. Others realized it saturated the rocks like water in a sponge and decided the oil could be gotten more quickly in a large pit than from a well. Thus began the modern concept of mining for oil.

DIG THAT BLACK GOLD! Digging for oil was not a new idea even when Drake drilled his famous well. Shafts and pits had been used successfully in Europe and Asia for centuries (Dickey, 1939). The early Indians of Venango and Warren Counties had dug pits along Oil Creek and other streams so long ago that it was not remembered by their descendants when the Europeans moved into the area in the 1600's. James M. Williams was digging producing oil shafts in Ontario in 1857, and in 1858, Colonel A. C. Ferris unsuccessfully sunk an oil shaft 220 feet deep at Tarentum in Allegheny County, Pa. The Pennsylvania Rock Oil Company's first attempts at commercial oil recovery along Oil Creek included digging pits and trenches to channel and trap the oil seeping out of the sand and gravel of the floodplain. So there was nothing new about the basic concept of mining for oil when the first attempt at deep mining in northwestern Pennsylvania was made in the Triumph Streak oil field at Tidioute in 1864.

IT'S ALL IN YOUR MINE. The Tidioute oil shaft was located across the Allegheny River from Tidioute in Warren County, about ¼ mile downstream from the bridge over the river (Carll, 1883). Begun in 1864, the 8- by 12-foot shaft encountered the oil reservoir, 5 feet of conglomeratic Venango Third sandstone (Figure 1), at 152 feet. Oil oozed from the 200 square feet of reservoir rock exposed in the floor and walls, but never enough to be productive. The company had wanted to run horizontal shafts into the sandstone, but the proj-

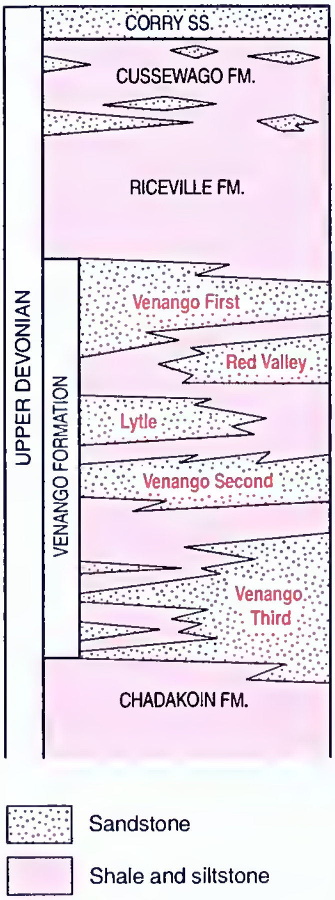

Figure 1. Generalized geologic column of the subsurface rocks of Venango County and adjacent areas.

ect was abandoned in the fall of 1865 when the foreman was killed in an accident and the workers refused to reenter the shaft.

At least five attempts at mining for oil were made in Ohio in 1865, three near Powers Corners, Trumbull County (Carll, 1880), and two near Macksburg, Washington County (Minshall, 1888). Because each shaft was dug at great expense, but only limited quantities of oil were recovered, they were all considered unsuccessful.

Perhaps the best known early experiment in oil mining, and the most ambitious, was the "Great Petroleum Shaft" at Petroleum Centre in 1865. It was also the least successful. The Petroleum Shaft and Mining Company hired 14 men for the project, including some Welsh miners from Schuylkill County, Pa. (Mong, 1994). The company planned a large pit to be dug 7 by 17 feet wide (12 by 17 feet according to some sources) and 500 feet deep to the prolific Venango Third sandstone reservoir (Figure 1). Diggers dug, and stonecutters and masons worked boulders into stable frameworks for the machinery. However, after only two months and at 73 feet "the funds ran out, gas threatened to asphyxiate the workmen, the big pumps could not exhaust the water and the absurd undertaking was abandoned" (McLaurin, 1896, p. 133). The fiasco became a local dump. Today the site (Figure 2), which is located in Oil Creek State Park on the southwest side of the road from Petroleum Centre to Plumer, about 1,000 feet southeast of the park office, is a circular pit that has been mostly filled in to protect farm animals.

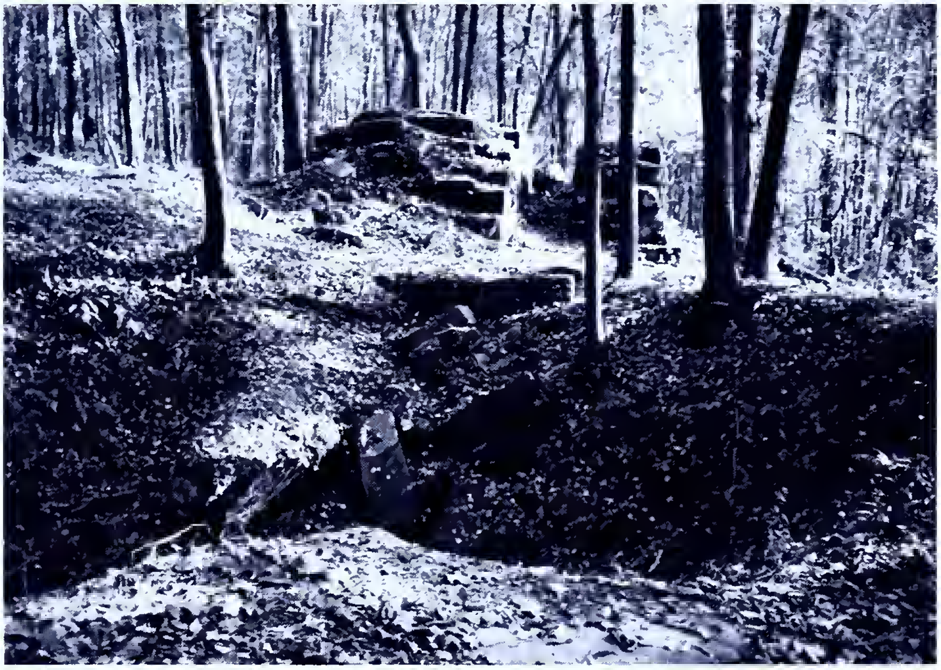

Figure 2. All that remains of the Great Petroleum Shaft is a 30-foot-deep depression and some stonework near the Oil Creek State Park office.

A CENTURY LATER. The Great Petroleum Shaft might have been an "absurd undertaking," but it certainly was not the last word in oil mining. With improved technology and a better understanding of subsurface geology, numerous companies around the world eventually tried and succeeded at mining for oil. Even Venango County was given two more chances, coincidentally at about the same time. In 1944, Northern Ordnance attempted a 580-foot shaft with a horizontal tunnel in the Venango Third sandstone along Bull Run, a tributary of Oil Creek, but the exorbitant cost of digging proved too much, and the project was abandoned at only 67 feet (Pees, 1989).

The Venango Development Corporation, a consortium of companies with familiar names such as Pennzoil, Quaker State, and Kendall, acquired a 400-acre lease about 3 miles north of Franklin. Then in 1942, they sank a 370-foot shaft near the center of the lease (Elder, 1944). The 8-foot-wide shaft was walled with steel and concrete. At the bottom, workmen excavated a room 27 feet in diameter and 59 feet deep, bringing the total depth of the shaft to 428.8 feet (Lytle, 1959). From this room, three rows each of 24 holes, each hole 6 inches in diameter, were cast into the concrete walls to be used for horizontal drilling into the Venango First sandstone (Figure 1). A tower supported an elevator that allowed workmen and equipment to enter and exit (Figure 3). The first oil flowed into a storage tank upon completion of the horizontal holes in 1943. The enterprise proved to be expensive, but eventually successful. The Franklin oil mine changed hands several times over the next 20 years, and an explosion in the 1950's damaged the project to the point where the main system had to be abandoned, and the project converted to a "conventional" oil well (Pees, 1989). Pennzoil, the final owner, ceased operations in 1967, and the project was finally plugged and abandoned in 1997.

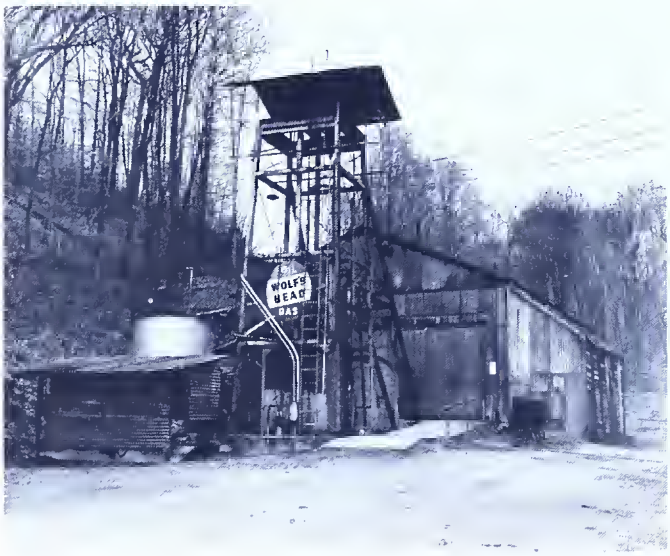

Figure 3. The Venango Development Corporation oil mine near Franklin as it looked in 1960. The tower supported the pipelines and elevator shaft. Photograph by William S. Lytle.

Valiant efforts often are in vain, but not always. The global oil industry had proven that oil could be extracted profitably by mining, and even in the nearly depleted oil fields of Pennsylvania, it became proven technology for a time. Is there another oil mine in Pennsylvania's future? Only time, and economics, will tell.

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The Science of Drilling Oil Wells

by Kathy J. Flaherty
Bureau of Topographic and Geologic Survey

[1]All around the walking beam,
The drillers search and toil.
That's where all the money goes. Blop! Goes the oil!

The location of Drake's famous oil well, and many of the wells that followed, were initially determined by the presence of promising "surface indications." Desirable surface indications included oil seeps that oozed from the surface of the earth and accumulations of oil that occurred in ancient pits dug by early Indian inhabitants. This primitive prospecting evolved into the pseudoscience of "creekology," or drilling near creek beds—or even in the creek. Creekology reflected the idea that oil accumulated in areas of low surface topography. Later, drillers believed that unless an open crevice was encountered during bedrock drilling, success was unlikely. This "crevice" theory represented the whimsical thought that oil occurred in underground streams, and shows an evolution in exploration approach from relying on surface observations toward utilizing subsurface data. Theories of oil occurrence and accumulation continued to unfold, guided by the creative imagination and monetary pursuits of the driller. Some geographic areas were revisited to test the new theories and the investors' billfolds; others were left to be "rediscovered" much later.

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[1] To the tune of "Pop! Goes the Weasel."

No matter what the current fad, the fact remained that drillers were paid to drill holes. In the frenzy to make wells profitable, drilling activity was not recorded. Time was of the essence, and the lure of strong oil flow created intense competition among drillers to be quicker with the drill bit. Without written observations of the subsurface penetrations, however, investors were literally rolling the dice with each new well. Poor records—or more likely, no records—led to haphazard drilling techniques, as evidenced by numerous dry holes in the same area and rapid reservoir depletion caused by needless and heedless overdrilling.

A dollar an acre pays the lease. More a deal will spoil.
That's the way the money goes. Blop! Goes the oil!

The early cultural and economic climates in the Pennsylvania oil fields were not conducive to creating records of the rocks encountered. John F. Carll, a geologist with the Pennsylvania Geological Survey during the early oil era, argued strongly for collection and maintenance of drilling data. In his 1880 report, Carll estimated that for every 100 wells drilled, less than one useful record was voluntarily submitted for the public files. Carll cited as causes of the unreliability of records the vast number of wells drilled (about 4,000 in 1877 in the oil fields of Pennsylvania and southern New York!) and the fact that so much data were recreated from memory long after the wells were completed. Drillers made money by drilling quickly, and sometimes the contracting company paid incentives to the driller and his crew to minimize drilling time. A low-cost, productive well was the goal of the contracting company. It took the budding industry many years to recognize that the path to success is geologic knowledge and interpretation through detailed observation.

Drill it quick with nary a thought.
To science they were not loyal.
A record may prove the theory wrong! Blop! Goes the oil!

Carll (1880) discussed the interests of the driller in "doctoring" well records. Paid by the number of holes completed, a shrewd driller could stretch the work for himself and his crew by merely drilling two or three "dry holes" first! Because the contracting company representatives rarely spent any appreciable time at a well site, a driller could easily misrepresent the results of a well by claiming a dry hole for a well that was not even drilled deep enough to reach the productive formation, or by misstating the characteristics of or the presence of the productive sandstone layers.

"Geological confusion" was not difficult to foster or maintain. Typically, drillers ignored the upper rock strata when drilling, and that readily led to stratigraphic correlation errors. Disorder was the order of the day: First, Second, Third, and Stray were prefixes assigned to sandstone layers without regard to where they occurred in the geologic section. Drillers introduced local subsurface rock names that led to problems of impossible correlation, including productive reservoirs seemingly isolated and distinct from each other. Carll recognized these frustrations and problems and sought to correct the situation by standardizing drilling records and by requesting that all bedrock encountered be described and measured during the drilling process. To the driller, this was an unreasonable demand on his time and on his earning potential!

Generally, records for wildcat wells were more complete and more accurate than those in development areas. However, no area was immune from the creative driller's record! The drillers' fear of investors recognizing their scam led to "fixed" records that appeared to follow the logical principals of the theory currently in vogue. With risk of exposure so high, records were forced to fit the picture the driller was trying to draw.

Landowners, too, had incentives for doctoring the drilling records. News of a dry hole did not inspire a company to pay rental on leases, drill, or pay royalties. It was typical for a landowner to say that an unproductive well on his land was not drilled deep enough to reach the oil sands!

A gusher is hard to hide in the hills. Publicity will foil. The best kept secret is over the top! Blop! Goes the oil!

Very successful wells—oil spurting over the top of the derrick and drenching everything in close proximity in a bath of crude (Figure 1)—made sensational news. As with all such events, sensation spreads quickly. Nothing was worse for the oil business than publicity, because publicity brought competition. News of good wells brought a scramble for nearby acreage, which the owner of the discovery well would want to secure for himself. Bizarre as it may seem, news of dry holes also brought competition for acreage, especially after the advent of the "belt" theories, in which it was thought that the productive oil sands occurred in linear trends. If a well was a duster, the belt must trend in a different direction, thus making the acreage in that direction more desirable. So, even with a dry hole there was a need to accumulate more acreage. Many a fortune was probably made by letting other drillers define productive limits of oil sand units by drilling mistakes! Even controlling a productive lease was no assurance that additional wells could be developed. Competitors crowded lease lines, infringing on the economics of offsetting prospects—an old "art" still very much practiced today.

To compete effectively, good, accurate, and timely geologic information was essential. In an industry shrouded in secrecy and deception, obtaining information became a specialized job: that of Well Scout. These enterprising folks were the oil-field spies and had the responsibility of discovering the status of wells in progress or the results of recently completed wells. They could be found snooping around a well in the woods—and in at least one case, a scout had to be rescued from under the floorboards of a derrick where he had become wedged after wriggling in in an effort to overhear and observe firsthand the goings-on at the well.

Accurate records,
carefully kept,
Of rocks and depth
and soil.
GEOLOGY should
guide the drill! Blop!
Goes the oil!

It became increasingly apparent that the consequence of selfishly guarding details of drilling and well results was an inefficient and ineffective use of resources for everyone. Carll was determined to solve the problem and created a "form" to be filled out during the drilling of each well. After all,

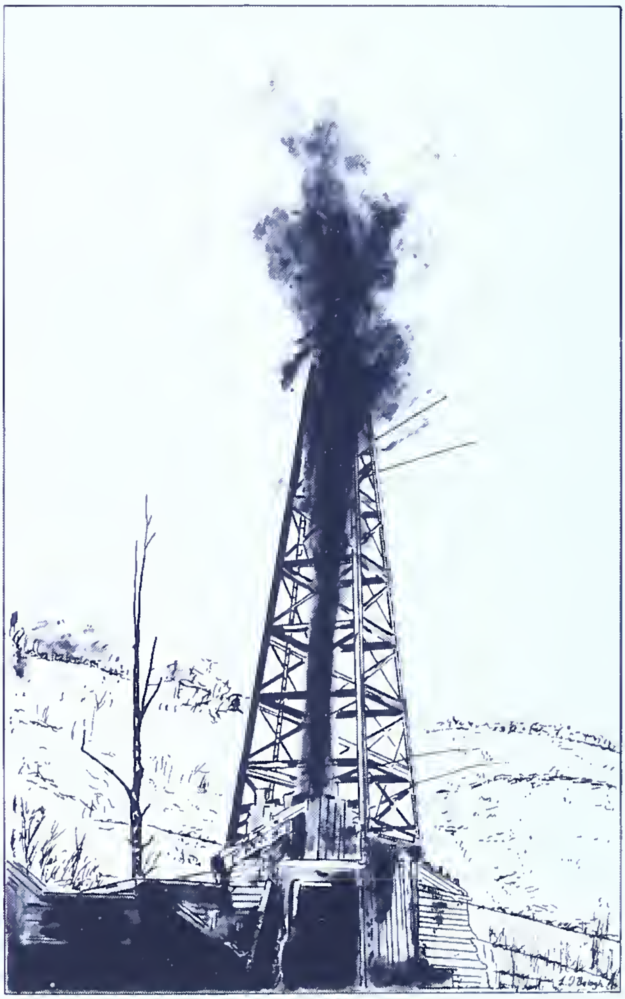

Figure 1. "Gushers" always made big news—and a big mess. Drawing by Lajos J. Balogh.

if accurate records were kept, there would be no excuses for dry holes! Particularly, Carll considered the depth and thickness of each type of rock drilled and the descriptions of the drill cuttings to be important. The value of collecting this data on a well-by-well basis was the foundation for building an understanding of the subsurface geology. This eventually and ultimately led to selecting drilling sites based on science rather than on whimsy. Comparing the drilling records of a sequence of wells could indicate a thickening or thinning trend in rock units, reveal uniform or changing characteristics in the oil reservoir rocks, and aid in correlation of local and remote areas by noting persistent marker beds. The concept was great, but Carll did not convince the drillers that such effort was worthwhile. In frustration, in 1876, Carll finally hired his nephew to visit certain well sites and take detailed notes and measurements for his personal study. Contracting companies eventually began to require measurements and details from drillers. Various methods of obtaining the information were employed, with varying degrees of accuracy; these methods gradually became more standardized and more reliable.

Many have drilled hither and yon,
To find a prospect royal.
There are still surprises in them thar hills!
Blop! Goes the oil!

Modern energy exploration, through the science of geology, has overcome many of the early problems to conscientiously and honorably meet the growing needs of society. Technology, coupled with keen observation and creative reasoning, has yielded oil where it was never before thought to have accumulated.

The role of the oil and gas industry in developing the science of geology and the technology of drilling should not be downplayed or misjudged. Much of what geologists know today about sedimentary rocks has only been gleaned through the efforts of energy companies and the scientists they employ. The search for subsurface hydrocarbons has yielded a treasure chest for understanding planet earth.

Modern exploration and drilling techniques have provided the tools to reassess the areas that deserve a new look. Although some areas of Venango County are already teeming with century-old boreholes, these are exciting and challenging times in the oil and gas industry, for much is yet to be discovered!

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ANNOUNCEMENT

Survey Sponsors "Geology Day" at Oil Creek State Park and Releases New Park Guide

The Bureau of Topographic and Geologic Survey, in cooperation with the Bureau of State Parks, the Bureau of Conservation and Recreation, and the Oil Heritage Region, Inc., will sponsor a "Geology Day" at Oil Creek State Park on Saturday, June 13, 1998. Geology Day is an opportunity for park visitors to learn about the geologic features of the Oil Heritage Region, including glaciation and the evolution of the landscape, local rock strata, fossils, erosion and other ongoing geologic processes, and the geologic story of Pennsylvania Grade crude oil. Events include, but are not limited to (1) a 19.4-mile bike hike along a well-paved former railroad grade from the park office at Petroleum Centre to the Drake Well Museum and back, with stops to look at rocks, fossils, landscapes, and oil history; (2) scheduled hikes along the moderately strenuous Geology Trail; (3) a fossil show-and-tell; and (4) an orienteering course (how to find where you are and where you are going using a topographic map and a compass), which includes demonstrations of a global-positioning-system (GPS) device. Staff from the Survey and Oil Creek State Park will be on hand to lead the events and answer questions. This is a great opportunity for individuals, families, and groups such as schools, scout troops, and clubs to learn about the geology of northwestern Pennsylvania and experience the wonderful outdoor environment of Oil Creek State Park.

A complete schedule of events is posted on the Survey's web site at <*www.dcnr.state.pa.us/topogeo/*> and is also available from the Pittsburgh office of the Survey (see facing page for address and telephone number).

Visitors to the park will be able to obtain a copy of the Survey's most recently published park guide in the "Trail of Geology" series. Park Guide 22, **Oil Creek State Park, Venango County—Ice and Oil Shape the Land,** by Survey geologist John A. Harper, was prepared in cooperation with the Bureau of State Parks. In the two-color, 12-page guide, Harper explains the effects of the Ice Age on the creek and the park's landscape and summarizes the geology and the history of the oil industry in the area. A centerfold map shows the locations of many sites of geologic interest. Park Guide 22 is a free publication and is available at Oil Creek State Park, or upon request from the Bureau of Topographic and Geologic Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. It is also posted on the Survey's web site.

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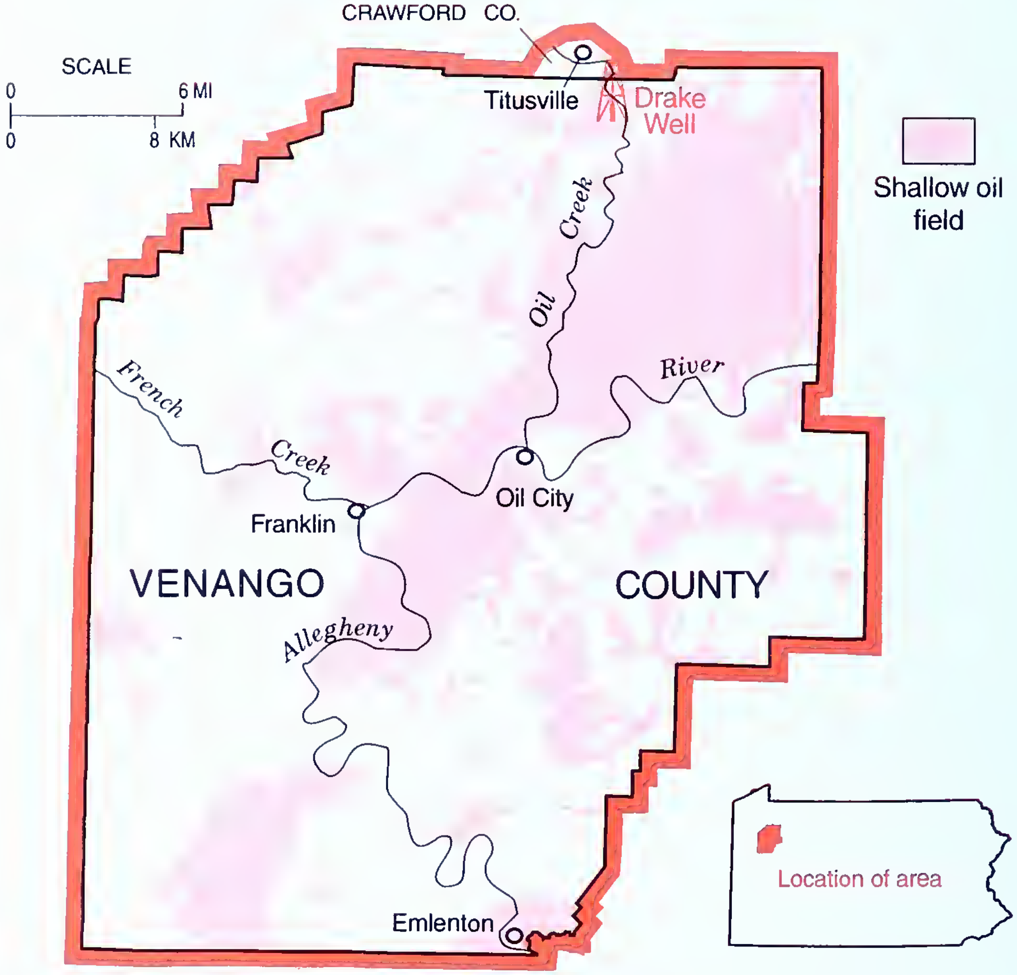

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CONTENTS

Reports and maps online—an update 1
Problematic tracks in the Casselman Formation of Cambria County 2
Mistakes of man: the Austin Dam disaster of 1911 7
New releases—Surficial geologic maps of the Allentown area 15
Announcement—Survey cosponsors sinkhole conference 16

ON THE COVER

Concrete blocks from the failed Austin Dam north of Austin, Potter County (see article on page 7). Photograph by C. A. Christ.

PENNSYLVANIA GEOLOGY

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STATE GEOLOGIST'S EDITORIAL

Reports and Maps Online—an Update

Over a year ago, I informed you that the DCNR's Bureau of Topographic and Geologic Survey had "published" an out-of-print report (Map 61, *Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania)* through the Internet, and that we hoped to use that venue for other out-of-print reports. We have achieved that goal and more. Other out-of-print reports and new digitally "published" reports are now available for your use.

In addition to Map 61, the public can visit our web site to access Open-File Report 97–04, *Directory of the Nonfuel-Mineral Producers in Pennsylvania.* Digital editions of *Pennsylvania Geology* and our frequently revised publications list (*Pennsylvania Geological Publications*) have also been available to you for some time at the click of your mouse.

Most recently, two more out-of-print reports that remain in high demand have been added to our site:

> General Geology Report 40, *Fossil Collecting In Pennsylvania.* This very popular report was last reprinted in 1988. For Internet distribution, this book has been organized into several sections that can be individually accessed.
>
> Environmental Geology Report 2, *Geology and Land Use.* Revision and republication of this report is planned because of its value in addressing geologic consequences of increased land use. Until a new edition is released, the present edition will be provided over the Internet.

As resources permit, more Bureau publications will be provided through the Internet. Together with the U.S. Geological Survey and libraries, we are planning to scan large-format topographic and geologic maps for digital distribution.

Please let us know of your needs. While we can't promise to provide all reports over the Internet, we will assess client needs and provide those in highest demand.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Problematic Tracks in the Casselman Formation of Cambria County

by William J. Marks
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Excavation of a privately owned borrow pit in Cambria Township, northern Cambria County (Figure 1), exposed a ripple-marked rock layer of the Casselman Formation containing a large (4-inch-by-12-foot) trackway of an unknown animal. This trackway has since been covered and is not available to be seen.

Trackways and burrows are traces of living creatures. They are called trace fossils if they are preserved in rocks. Palichnology is the study of trace fossils. The identification and interpretation of trace fossils is often problematic. Paleoenvironments that preserved tracks, but were not favorable for the preservation of skeletal remains, were common in geologic history. For example, Triassic rocks of the Connecticut Valley are abundant in dinosaur tracks but yield few fossil remains. Tracks and trails are often credited to crawling organisms. Rare exceptions occur where the organism has been fossilized with the tracks, such as *Mesolimulus walchi* (a horseshoe crab) found in the Solenhofen Limestone, Bavaria (Leich, 1965).

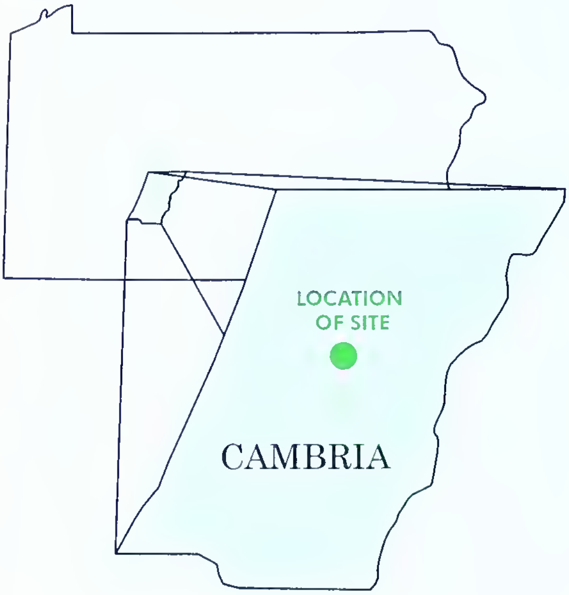


Figure 1. General location of site.

STRATIGRAPHY AND PALEOENVIRONMENTS. The youngest rocks in Cambria County are Pennsylvanian in age, and the Casselman Formation in the Conemaugh Group is the youngest of the Pennsylvanian-age strata (Figure 2). Two distinct lithologies are exposed at the site: a sandstone containing current ripple marks, and a shale that overlies the sandstone. The contact between the sandstone and the shale is sharp. It is on the surface of the sandstone that the trace fossils and ripple marks occur.

An approximately 30-foot square area on the top of the sandstone was cleaned for observation and study with the consent of the property owner (Figure 3). At this horizon, numerous ripple marks were preserved.

SYS-TEM	STRATIGRAPHIC UNIT	
PENNSYLVANIAN	Conemaugh Group	Casselman Formation
		Glenshaw Formation
	Allegheny Formation	
	Pottsville Formation	

Figure 2. Stratigraphic units of the Pennsylvanian System in Cambria County.

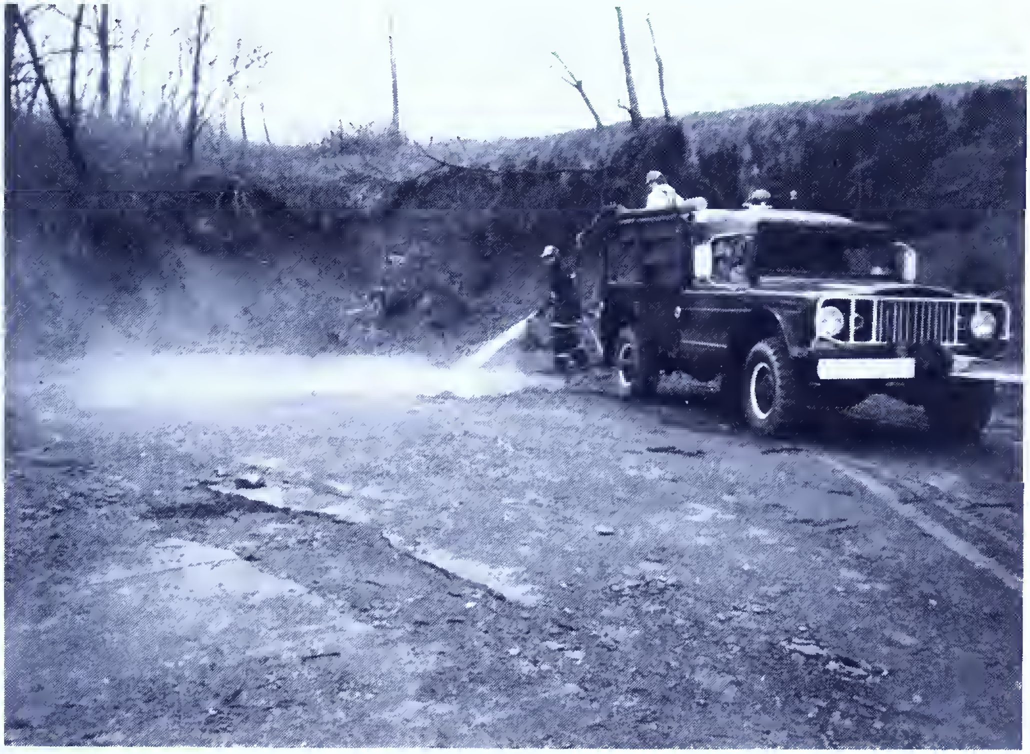


Figure 3. Local fire department cleaning the top of the sandstone.

DESCRIPTION OF THE TRACKWAY. The trackway was exposed for approximately 12 feet to a point where it intersected the highwall of the pit (Figure 4). The trackway consisted of two 1-inch-wide parallel rows of marks that maintained a separation of 4 inches throughout its exposed 12-foot extent. The consistency of the parallelism of the rows, including around a gradual turn, indicates that one organism produced the trackway. The trackway obliquely crossed and modified the ripple marks and thus was created later than the ripple marks (Figure 5).

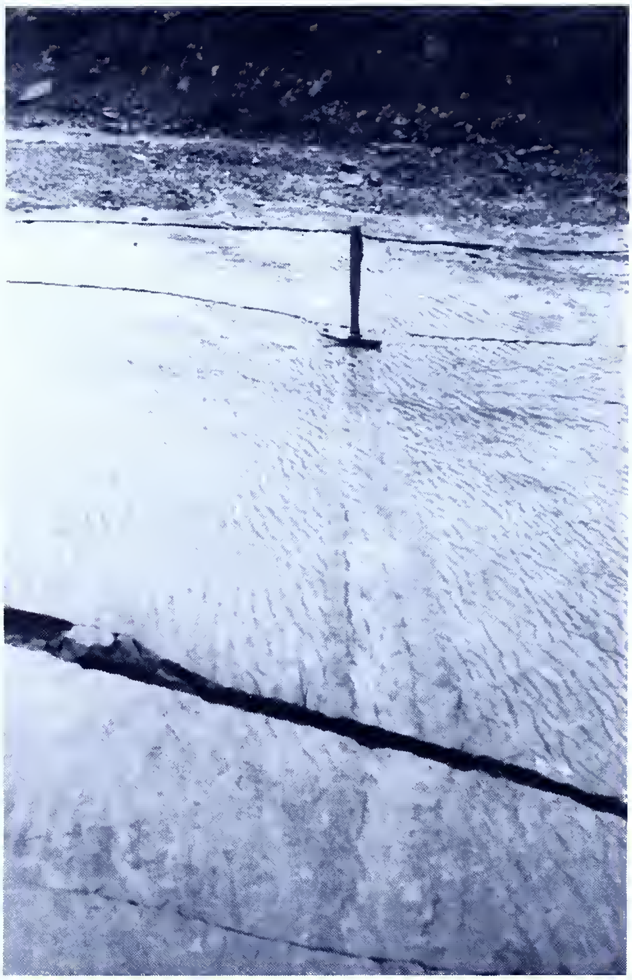
Each row of marks in the trackway was different. In Figure 5, the row on the left consists of rounded, lobate impressions. The parallel row on the right consists of spiky, sawtooth impressions. Figure 6 shows a close-up of the marks.

The dissimilar appearance of the two rows of the trackway complicates assigning its origin to a specific animal class. However, parallel, dissimilar tracks are also observed in modern sediment. For example, Xiphosurans (horseshoe crabs), which are frequently seen along eastern United States coastlines, pair while mating and travel attached for considerable distances, producing parallel, dissimilar tracks. The trackway in the Casselman Formation is believed to be the result of a single organism that moved along the sand-water interface causing deformation of one side (spiky, sawtooth side) of the trackway and resulting in dissimilar markings. An unblemished trackway would consist of rounded, lobate impressions. This sand-water interface was likely a prime source of food for these creatures.

The origin of the type of trackway described herein is difficult to establish in rocks that are 300 million years old. Few of the animal types alive back then have modern descendants. However, similar

Figure 4. Two parallel rows of marks (to right of tape measure) make up the trackway. Lines at top show a gradual turn near the highwall. Length of tape is 10½ feet.

Figure 5. Trackway cross-cutting ripple marks in the Casselman Formation. Hammer, on the trackway, shows scale.



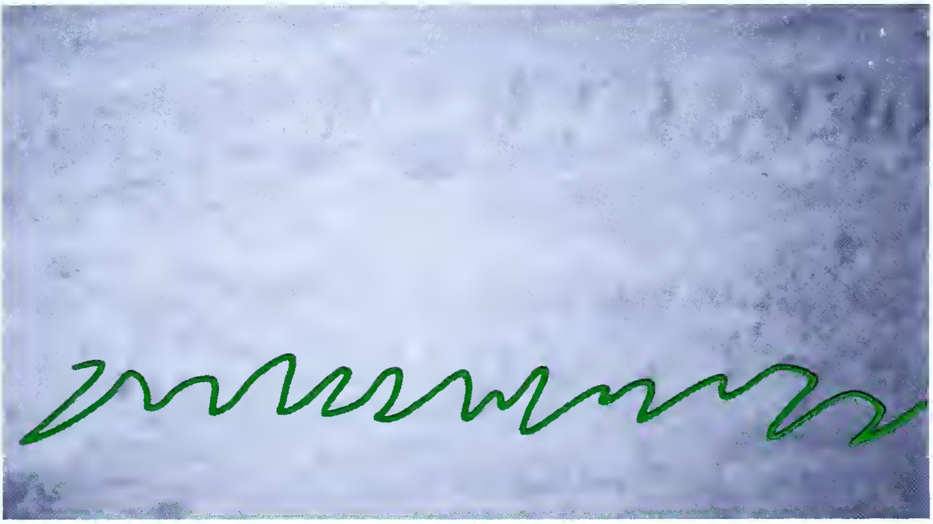


Figure 6. Close-up of lobate track (top) and spiky track (bottom). The spikes are highlighted by the colored line.

trackways have been described in similar-age rocks in Fife, Scotland (Pearson, 1992). In these rocks, dual rows of rounded lobate impressions of a similar size and shape to the Cambria County trackway were attributed to a giant myriapod (arthropleurid) by Briggs and others (1979) and were illustrated in Plate 30 of their report. Myriapods include such modern, jointed-leg invertebrates as millipedes and centipedes (Figure 7).

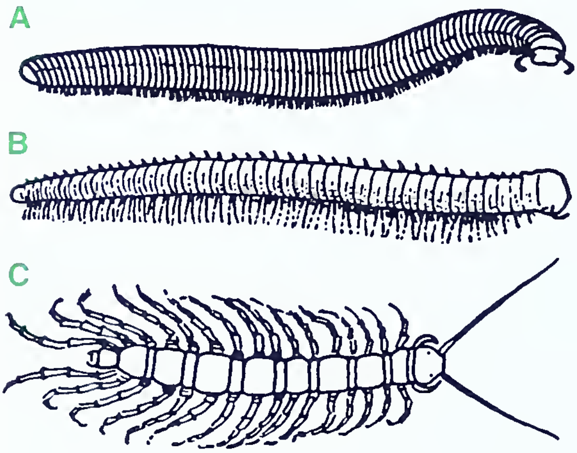


Figure 7. Sketches of myriapods (from Moore and others, Invertebrate fossils, ©1952, The McGraw-Hill Companies, p. 567). Reproduced with permission of The McGraw-Hill Companies.

A. Present-day millipede.
B. A reconstruction of a Paleozoic millipede.
C. Present-day centipede.

A British Broadcasting Corporation television documentary, "Lost Worlds, Vanished Lives," which aired on the Turner Broadcasting System network, featured a myriapod trackway on the Isle of Arran in western Scotland. This trackway also resembles the Cambria County trackway in that it displays lobate impressions. The Arran trackway was interpreted by the program's scientific consultant, Ian Rolfe, to have been created by a myriapod approximately 6 feet in length.

Based on the similar size and shape of the trackways and on the time-stratigraphic correlation between the Casselman Formation sandstone and rocks of similar lithology in Scotland, the authors interpret that the Cambria County trackway was caused by a giant myriapod walking over rippled sediment.

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Mistakes of Man:
THE AUSTIN DAM DISASTER OF 1911

by Brian H. Greene and Courtney A. Christ
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INTRODUCTION. Austin Dam was a concrete structure located in Potter County near the town of Austin, Pa. The dam failed catastrophically on September 30, 1911, killing 78 people in the downstream communities of Austin and Costello, Pa. The tragic demise of Austin Dam represents the second worst dam failure (in terms of loss of life) to occur in the Commonwealth of Pennsylvania. The worst Pennsylvania dam failure occurred at Johnstown in 1889. This article summarizes the sequence of events and adverse geologic site conditions that contributed to the failure of the dam.

GEOLOGIC SETTING. Austin Dam is located in Potter County, Pa., as shown on Figure 1. Potter County is in the Appalachian Plateaus physiographic province and contains the headwaters of the Genesee River, the Allegheny River, and the Susquehanna River. As such, the region is a deeply dissected plateau, having extensive areas of steep slopes separated by narrow ridges. Near the junction of the three aforementioned watersheds, the upland areas rise to an elevation of more than 2,500 feet above sea level. Potter County is underlain principally by sandstone, siltstone, shale, conglomerate, and minor amounts of coal and carbonate rocks, ranging in age from Late Devonian to Middle Pennsylvanian (approximately 385 to 320 million years old). The rocks are broadly warped into a series of open folds that strike northeast-southwest.

Austin Dam is situated within an area of Potter County that is unglaciated (Denny, 1956). Bedrock underlying the dam site consists of horizontally layered sedimentary rocks; principally sandstones and shales of the Devonian-age Catskill Formation. The bedrock geology of the Austin Dam area is depicted on the "Emporium 15' NE" map of Map 61 (Berg and Dodge, 1981, p. 198), which is available on-line at <www.dcnr.state.pa.us/topogeo/map61/61intro.htm>. Figure 2 shows a generalized geologic column for Potter County, on which Austin Dam foundation rocks are indicated. The dam's foundation was described

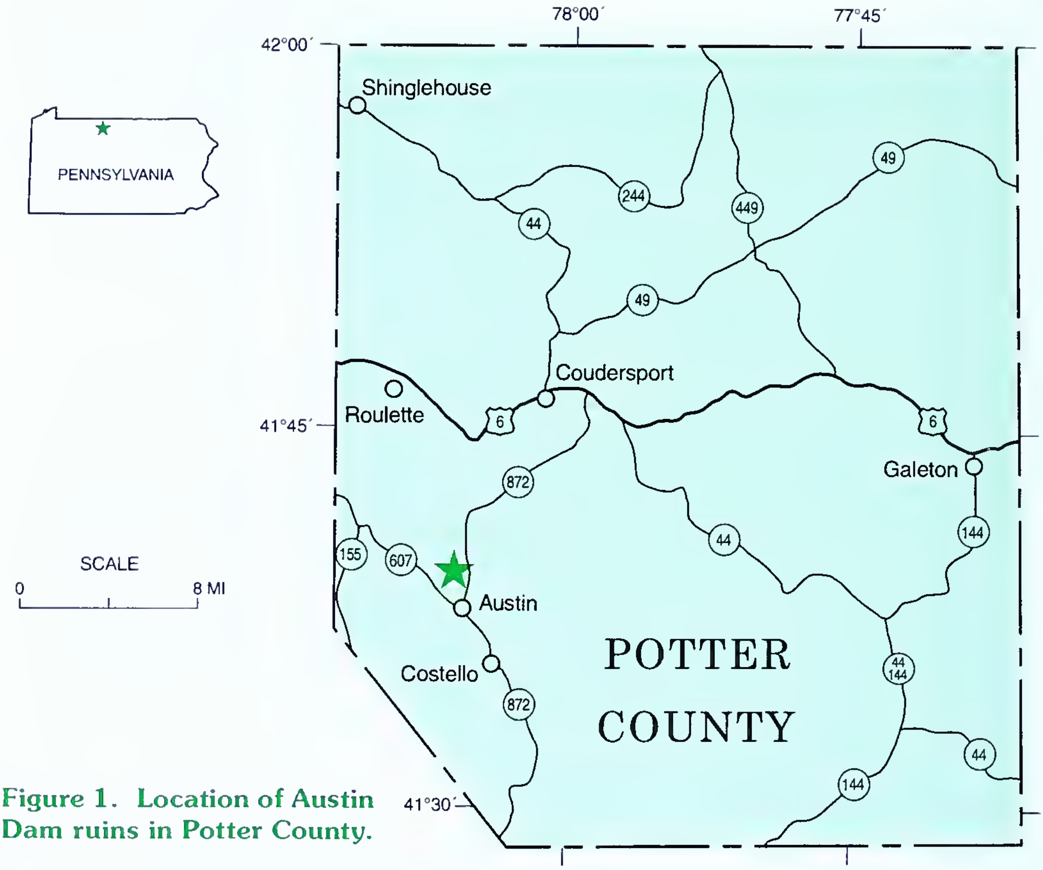

Figure 1. Location of Austin Dam ruins in Potter County.

in Anonymous (1911) as being constructed on a 2-foot-thick layer of sandstone. The brief description also indicated that the dam's foundation was very shallow, workers excavating only 4 feet of shale to reach the sandstone. Because the area is unglaciated, bedrock, in places, is deeply weathered.

DAM CONSTRUCTION. The construction of Austin Dam began in 1909 when a local paper mill, owned by the Bayless Pulp and Paper Company, needed to impound water for its processing operations. The dam was to form a reservoir on a small stream called Freeman's Run, which has a watershed of approximately 85 square miles. Flow from this small watershed ultimately drains into the Susquehanna River. Because this was a gravity-type dam, it relied on sheer weight (gravity) to ensure its stability and long-term performance. The dam was constructed of concrete, was about 540 feet in length, and rose to about 50 feet above the valley bottom. When the dam was completed in December of 1909, about 16,000 cubic yards of concrete had been placed, and a reservoir of 200 million gallons of water was soon impounded.

AGE	ROCK UNIT	
PENNSYL-VANIAN	Pottsville Formation: Predominantly gray sandstone and conglomerate; some thin beds of shale, claystone, limestone, and coal.	
MISSISSIPPIAN	*Missing section*	
	Burgoon Sandstone: Buff, medium-grained, crossbedded sandstone; in places, conglomerate at base.	
	Huntley Mountain Formation: Greenish-gray and light-olive-gray, flaggy, fine-grained sandstone and a few red shale interbeds.	
DEVONIAN	Catskill Formation: Succession of grayish-red sandstone, siltstone, and shale, generally in fining-upward cycles; some gray sandstone and conglomerate.	
	Chadakoin Formation: Light-gray or brownish siltstone and some sandstone, interbedded with medium-gray shale.	Lock Haven Formation: Interbedded olive-gray sandstone, siltstone, claystone, and thin conglomerate.

Figure 2. Generalized geologic column of surface bedrock in Potter County. The foundation rocks of Austin Dam are highlighted in color.

IMPENDING DOOM. In late January 1910, less than two months after the dam had been placed into operation, there was a major rainstorm, and the dam's reservoir was full of water. During this flood event, dam operators observed that a large quantity of water was upwelling in the area immediately downstream of the toe of the new dam. In addition, they observed that the dam had developed six prominent, vertical cracks and the top center portion of the dam bowed downstream about 30 inches (Anonymous, 1911). Because the dam had not been constructed with any preformed concrete joints, the six vertical cracks divided the dam into seven separate segments. Some local townspeople felt that this evidence of distress could be attributed to the assumption that the concrete had not completely cured. The dam had no spillway or gates to release water in a controlled manner; therefore, in order to reduce the height of water behind the dam, the owner dynamited the top portion of concrete at the downstream right abutment. Afterward, no major repairs were made to the dam, other than to replace the concrete blasted out, and the reservoir returned to normal pool over a period of a few months.

THE DAY OF THE DISASTER. Saturday, September 30, 1911, was a warm day in the town of Austin. The townspeople were busy shopping downtown, and a local primary election was being held. Workers at the lumber mill located between the town and the dam were busy cutting and stacking lumber. At 2:15 in the afternoon, the mill's whistle blew, warning the town of a problem. Some residents left their homes seeking higher ground; however, others disregarded the signal. Shortly after the whistle blew, a wall of water surged through the town, carrying with it a vast amount of logs and cut lumber from the mill. The wall of water and debris devastated the town, knocking down wood-frame, brick, and masonry structures alike. The debris wave was described by one survivor, who was viewing the valley from a hillside, as being like a "huge slithering snake" ricocheting down the sinuous valley, moving up one hillside and sliding down another (Nushke, 1960). The debris mass moved slowly, damming water behind it and increasing in volume as it engulfed streets, buildings, bridges, and everything else in its path. When the flood had passed, 78 people, most of them from Austin, had perished.

AFTERMATH OF THE DISASTER. For many weeks, survivors of the flood and residents of adjacent towns and villages dug through the wreckage and debris in a heartbreaking search for bodies. The recovery of bodies progressed from that last day in September through late December. News of the dam failure spread throughout the country and throughout the world. Reports of the disaster appeared in the newspapers of many American and European cities. President William Taft sent words of condolences and an offer of federal aid to the town's survivors.

An editor by the name of F. E. Schmitt was dispatched by the New York City publication *Engineering News* to report on the details of the disaster. Schmitt's investigation of the dam's construction and of evidence available in the remaining pieces of wreckage significantly helped to unravel the cause of the failure. Schmitt's field reports were used to reconstruct the events in Austin and how the dam had broken apart. Figure 3A is a cross section of the failed dam as it appeared immediately after the failure (and also how it appears today). As shown on this figure, there were two main breaches of the dam structure. Figure 3B displays the wreckage in plan view and gives a perspective of how far individual concrete blocks (labeled A through G) moved downstream. Upon examination of the failed structure, Schmitt concluded "the whole appearance of the wreck points directly to a slid-

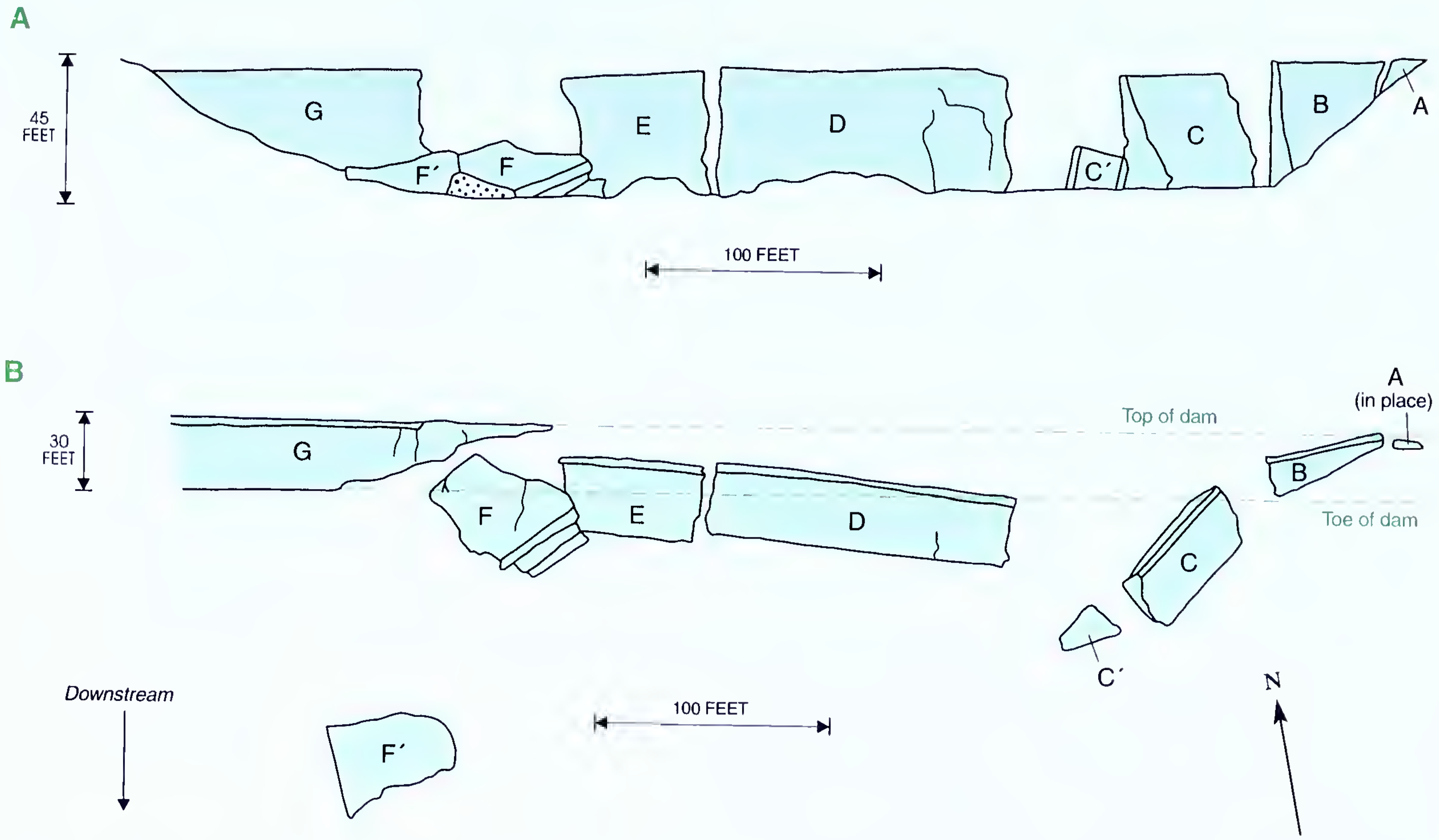

Figure 3. Views of the failed dam showing individual blocks labeled A through G (modified from Anonymous, 1911): A, cross section looking upstream; B, plan view.

ing failure" (Anonymous, 1911). In a sliding failure, the concrete structure slides horizontally on its rock foundation. At the present-day site of the dam ruins, it can be clearly seen that the failed blocks of concrete slid in a downstream direction and rotated on their base.

Site geology and the geologic materials upon which the dam was constructed certainly played a major role in the failure (Figure 4). At the location of the gap between two concrete sections there was what Schmitt described as "remarkably upfolded and crumpled masses of laminated shale strata suggesting a great downstream pressure" (Anonymous, 1911). In essence, individual blocks of concrete bound by vertical cracks were pushed downstream and, in places, bulldozed the shale bedrock upon and against which the dam was built. The horizontal force of the reservoir water acting on the upstream face of the dam overcame the resistance to sliding offered by the force of the concrete dam sitting on rock. Postfailure analysis clearly showed that the plane of sliding developed in the shale underlying the sandstone, which represented the weakest zone in the foundation (Greene, 1997). In essence, the upper sandstone layer slid downstream along with the concrete blocks comprising the dam. This was a classic foundation failure in which the dam failed by sliding. The foundation failure led to the failure of the structure itself.

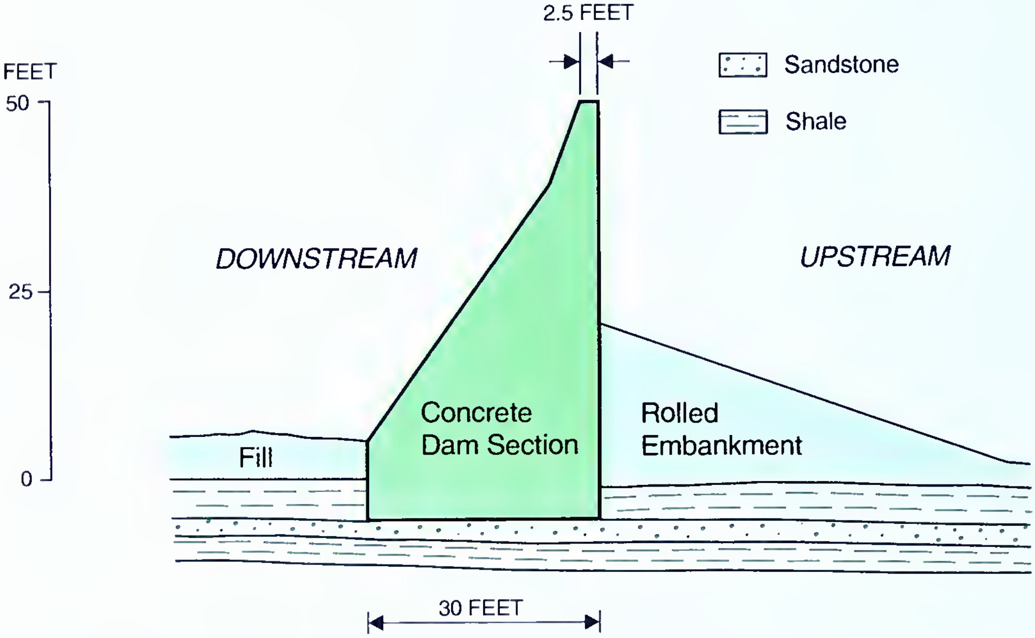

Figure 4. Prefailure cross section of Austin Dam at Block "D."

CONCLUSION. The failure of Austin Dam was truly a tragic incident in the history of the commonwealth. Although the dam's designer thought he had a suitable foundation for the structure, he failed to recognize that it had not been taken deep enough to prevent underseepage. The foundation rock was described as sandstone; however, the thickness of the sandstone layer was only 2 feet.

Geology played a major part in the disaster at Austin. Had the dam's foundation been taken deeper into bedrock, it may have prevented the underseepage that ultimately brought about the high uplift condition that caused the structure to become unstable. Uplift pressure reduces the effective weight, and therefore the stability, of a concrete dam. When the effective weight of a dam is reduced, the horizontal force of the water load is able to move the structure. In addition, had the foundation been taken below the shale layer (where the sliding plane developed), the dam's stability would have been significantly enhanced. In an article written by the project design engineer, Mr. T. Chalkley Hatton, it is stated, "The failure of this dam was not the result of poor workmanship, but poor judgment upon my part in determining its foundation. I should have sought the advice of a man more skilled in determining foundations for dams than myself." Hatton went on to say, "The great mistake I made in building this dam was trusting the rock foundation to be impervious." (Hatton, 1912). It should be pointed out, however, that Hatton designed and built this dam under considerable constraints imposed on him by the owner. In particular, Hatton had designed a foundation cutoff wall that was to be taken to a sufficient depth into bedrock to prevent underseepage. He was overruled on this critical design feature because of the owner's concern about the additional expense involved.

Not surprisingly, very soon after the failure of Austin Dam, legislation was enacted in Pennsylvania calling for state supervision of the design, construction, and operation of dams and reservoirs within the commonwealth. A comprehensive dam safety program was thus initiated in Pennsylvania to prevent the recurrences of disasters such as those suffered at Johnstown and Austin. The failure of the dam at Austin not only raised awareness of dam safety but also taught designers of dams worldwide valuable lessons as to what is needed to prevent this type of tragedy in the future.

The remnants of the failed dam remain in place today and can be easily viewed and accessed from Pa. Route 872 north of the town of Austin (Figures 1 and 5). The ruins are just a short hike from the road, and there are no nearby dwellings.

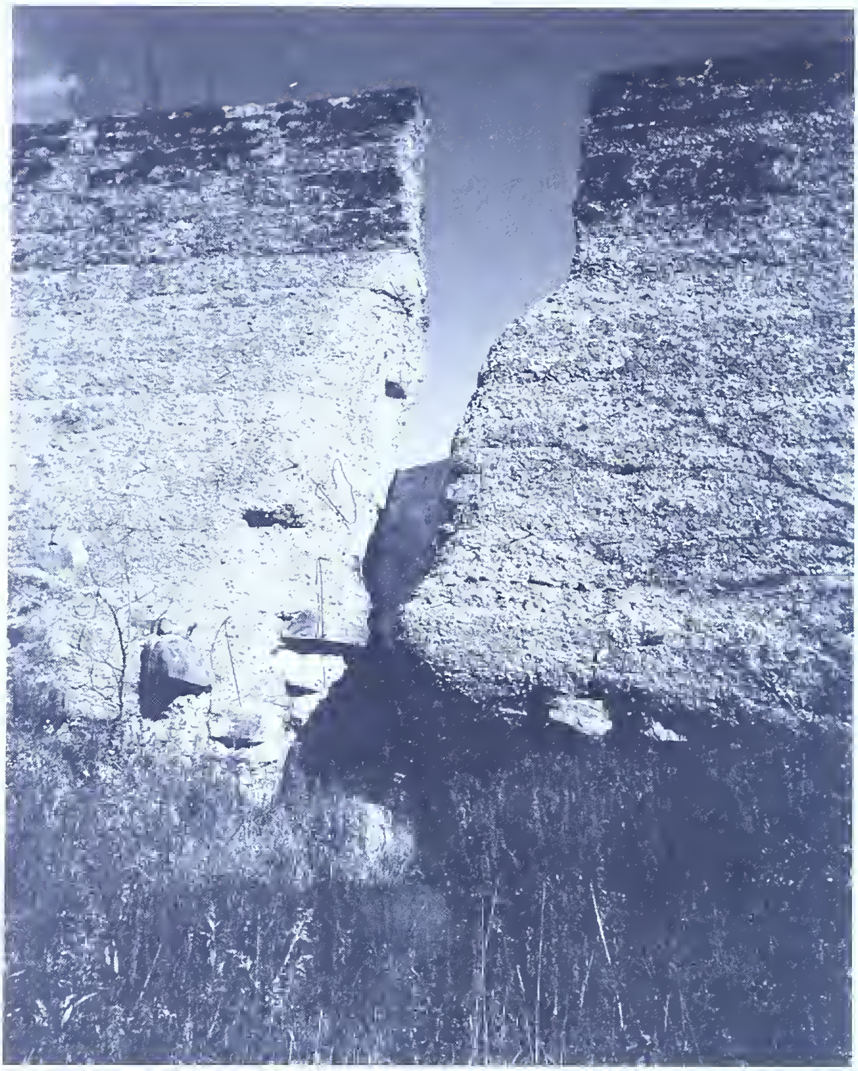

Figure 5. Downstream face of concrete sections from the failed dam.

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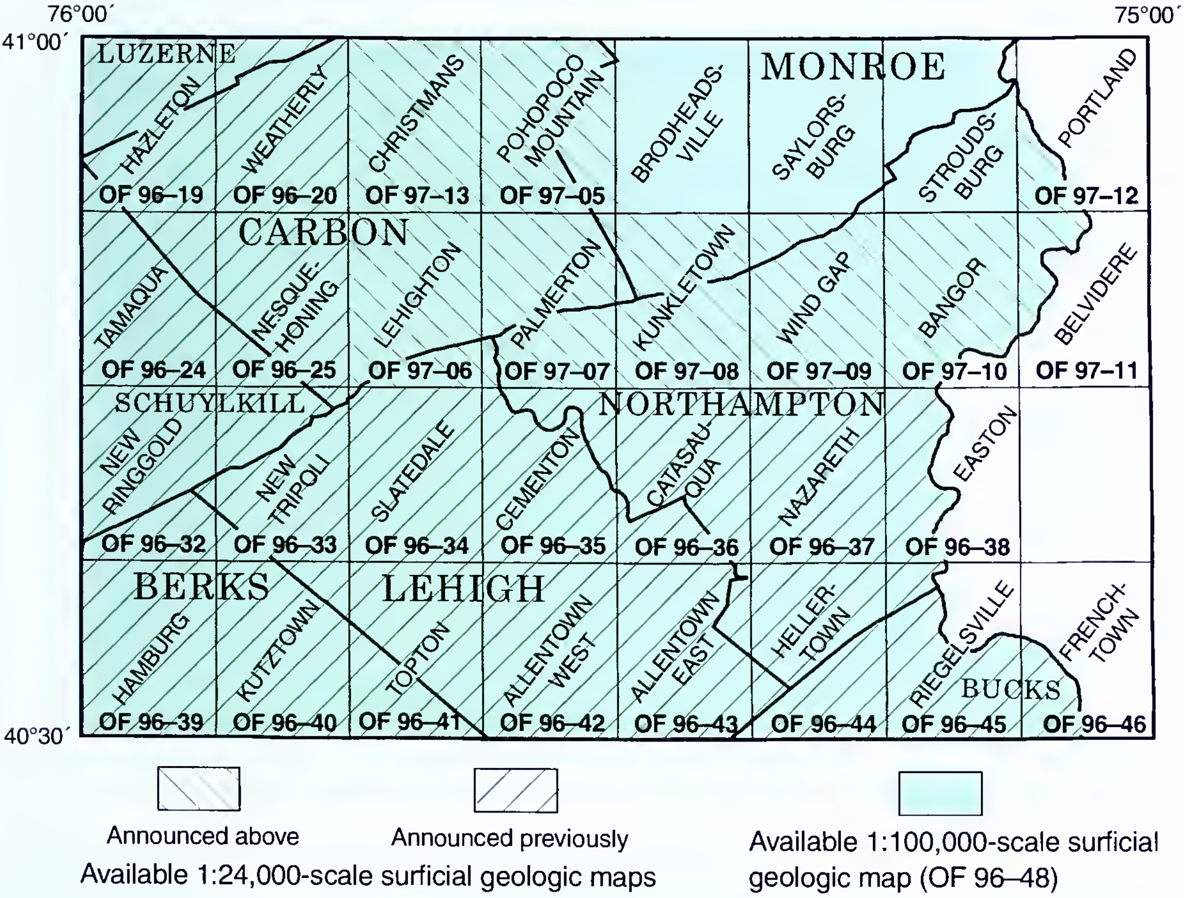
NEW RELEASES

Surficial Geologic Maps of the Allentown Area

Twenty-eight open-file reports showing surficial geology at a scale of 1:24,000 in the area of the Allentown 30- by 60-minute quadrangle are now available from the Bureau of Topographic and Geologic Survey (see figure below). Nineteen of these reports were previously announced in *Pennsylvania Geology* (v. 27, no. 3, and v. 28, no. 1/2). Of the new reports, OF 97–05—97–09 and OF 97–13 are by D. D. Braun of Bloomsburg University, Bloomsburg, Pa.; OF 97–10 is by Braun and J. C. Ridge of Tufts University, Medford, Mass.; and OF 97–11 and OF 97–12 are by Ridge and Braun.

In addition to these maps, the Survey has released a 1:100,000-scale surficial geologic map for the area. **Open-File Report 96–48, Surficial Geology of the Allentown 30 x 60-Minute Quadrangle,**



was compiled by D. D. Braun from 1:24,000-scale maps.

All of the reports consist of an uncolored photocopy of surficial geologic units hand drawn on a topographic quadrangle base map. The maps are accompanied by a short (3 to 9 pages for the 1:24,000-scale maps and 17 pages for the 1:100,000-scale map) text containing detailed descriptions of the surficial geologic units and a short discussion of mapping methodology and previous work. The reports with 1:24,000-scale maps, except for OF 97–11 and OF 97–12, include a table showing the relationship between mapping units and county soil series. Open-File Report 96–48 includes a figure showing physiographic divisions and another figure showing glacial boundaries in the area.

The reports may be purchased from Open-File Sales, Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453: OF 97–04—97–13 are **$2.50 each, plus $0.15 sales tax** for Pennsylvania residents, and OF 96–48 is **$3.00, plus $0.18 sales tax.** Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*. The reports may be examined in the Bureau's library at 1500 North Third Street, Harrisburg, and in the Pittsburgh office of the Bureau at 500 Waterfront Drive.

For further information on open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–783–7262.

ANNOUNCEMENT

Survey Cosponsors Sinkhole Conference

The *Seventh Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst*™ will be held in Harrisburg, Pa., April 10–14, 1999. It will feature a keynote address by Dr. William B. White of Pennsylvania State University, a renowned karst expert.

This year's conference will focus on applied science or engineering practices in karstlands. A special session entitled *Impacts of Sinkholes and Karst on Highways* will cover planning, design, and construction procedures used to avoid or mitigate karst-related problems along roadways. There will be two optional activities at the conference: an *Introductory Short Course on Applied Karst Geology and Hydrology* and a field trip through the Great Valley of Pennsylvania.

For more information, including a list of sponsors, visit the conference web site at <www.uakron.edu/geology/karstwaters/7th.html> or call Ms. J. Gayle Herring of P. E. LaMoreaux and Associates, Inc., at 423–483–7483.

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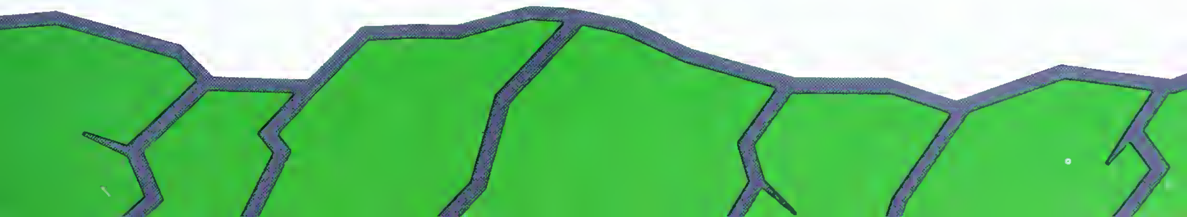

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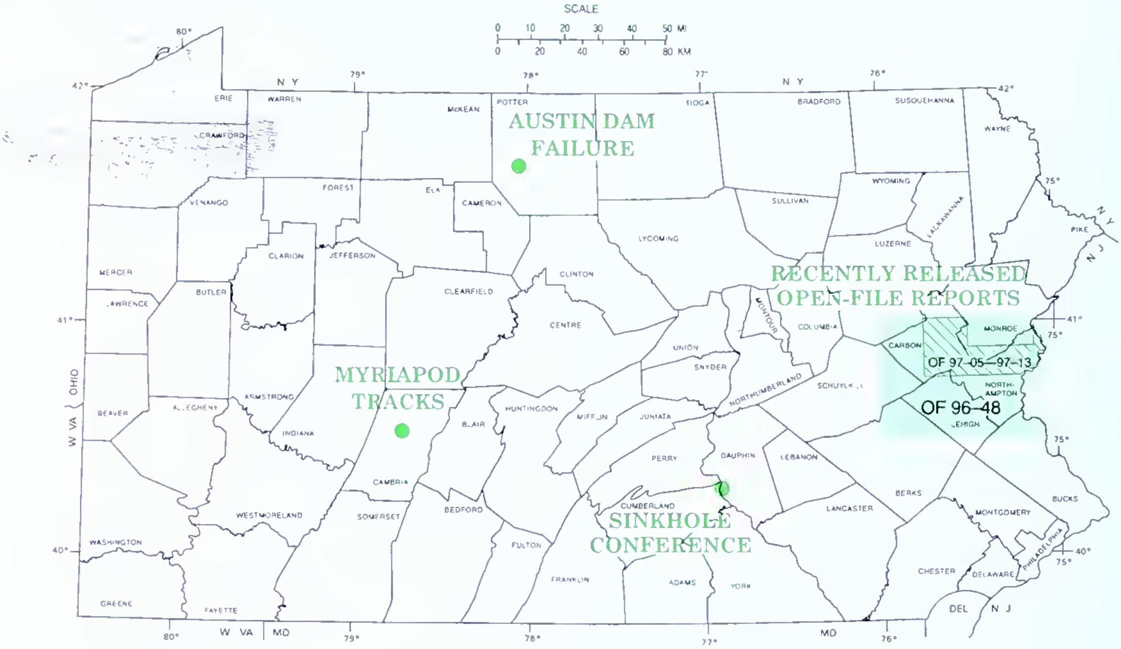

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CONTENTS

A natural geologic event 1
Preliminary results from the investigation of the Pymatuning earthquake of September 25, 1998 2
New releases 14
  Rocks and ruins of the "Upper Grand" 14
  Two new groundwater resource reports available 15

ON THE COVER

Items knocked off the shelves at the Golden Dawn Supermarket, Jamestown, Pa., by the Pymatuning earthquake (see article on page 2). Photograph by Regis Shawkey, September 25, 1998.

PENNSYLVANIA GEOLOGY

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STATE GEOLOGIST'S EDITORIAL

A Natural Geologic Event

On September 25, 1998, a natural geologic event—an earthquake—occurred in Pennsylvania. This natural event was significant for two reasons. First, its magnitude (5.2) was the highest ever recorded in Pennsylvania. Second, it occurred in an area of western Pennsylvania that only rarely experiences such events. Most prior Pennsylvania earthquakes of appreciable magnitude have occurred in or near Lancaster County in southeastern Pennsylvania.

The September 25 earthquake epicenter was located near the Crawford County community of Greenville, close to the Ohio-Pennsylvania border and near the south end of Pymatuning Lake, from which has come its name.

Much of this issue of *Pennsylvania Geology* is devoted to a description of the Pymatuning earthquake and the efforts by geologists and hydrogeologists to explain it and its effects. Some of the descriptions are technical but necessary to accurately portray the event.

However, the story of this earthquake has not ended with this issue, because we continue to track and investigate its results, which affected at least one of Pennsylvania's most precious resources—its groundwater. As is described herein, many water wells that provide this important resource for household use were damaged. Many homeowners were required to drill new wells or deepen existing wells at significant personal cost.

Within a few days of the event, using the new digital technology of the World Wide Web, a web page was created and "published" by geologists of the U.S. Geological Survey (USGS). For more information than can be presented in this issue, please visit this web site at *<http://groundmotion.cr.usgs.gov/pym/pym.htm>*, as well as the companion web page provided by the Pennsylvania Bureau of Topographic and Geologic Survey at *<http://dncr.state.pa.us/topogeo/hazards/greenville.htm>*. As more information is obtained through continuing cooperative investigations by the USGS and Bureau hydrogeologists, it will be provided on these web sites.

In cooperation with the USGS and adjoining state geological surveys, we have developed a detailed database of recorded and historical earthquake events. A map of earthquake epicenters based on this database is available at *<http://dcnr.state.pa.us/topogeo/hazards/epimap.gif>*.

Donald M. Hoskins

Donald M. Hoskins
State Geologist

Preliminary Results from the Investigation of the Pymatuning Earthquake of September 25, 1998

John Armbruster[1], Henry Barton[2], Paul Bodin[3], Theodore Buckwalter[4], Jon Cox[5], Edward Cranswick[5], James Dewey[5], Gary Fleeger[6], Margaret Hopper[5], Stephen Horton[3], Donald Hoskins[6], Deborah Kilb[3], Mark Meremonte[5], Ann Metzger[3], Dennis Risser[7], Leonardo Seeber[1], Kaye Shedlock[5], Katherine Stanley[2], Mitchell Withers[3], Madeleine Zirbes[5]

INTRODUCTION. The Pymatuning earthquake occurred on Friday, September 25, 1998, at 19:52:52 Universal Coordinated Time (UTC), or 3:52:52 p.m. EDT, near Jamestown, Pa., at the southern end of the Pymatuning Reservoir, which straddles the Ohio-Pennsylvania border. The National Earthquake Information Center (NEIC) determined that the event had a magnitude of 5.2 mbLg (a magnitude scale used to measure the size of earthquakes that are regional distances away [100 to 1,000 km, or 60 to 600 mi]), an epicenter of 41.5°N latitude, 80.4°W longitude, and an estimated depth of 5 km (3 mi). One person was reported injured as a result of being thrown to the ground by the earthquake, and it caused minor damage to buildings and seriously disrupted many water wells in the Greenville-Jamestown, Pa., area. The earthquake was generally felt over an area of approximately 200,000 km^2 (77,230 mi^2) throughout northern Ohio, western Pennsylvania and New York, and much of southern Ontario, Canada (see map on back cover). It was also felt as far west as Illinois and Wisconsin, as far east as New Jersey, Connecticut, and the District of Columbia, and as far south as Kentucky and Virginia. During the aftershock field investigation that commenced within 12 hours of the main shock, a World Wide Web site, <*http://groundmotion.cr.usgs.gov/pym/pym.htm*>, was established from the field headquarters. The web site was used not only to transmit investigation results to the world in near real time but also to receive information from the local community as new earthquake effects were reported. As of March 1999, at least 11 aftershocks have occurred, the largest being a magnitude 2.3.

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[2] Thiel College, Greenville, Pa.

[3] Center for Earthquake Research and Information, University of Memphis, Tenn.

[4] U.S. Geological Survey, Water Resources Division, Pittsburgh, Pa.

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The largest recent previous earthquake in the region was the northeastern Ohio (Leroy) earthquake of magnitude 5.0 that occurred on January 31, 1986, about 65 km (40 mi) west-northwest of the Pymatuning shock. This event was also felt by many of those who felt the Pymatuning earthquake. Similar to most of the seismicity east of the Rocky Mountains, earthquakes in the region are probably shallow (5 to 10 km, or 3 to 6 mi), and Seeber and Armbruster (1993) hypothesized that the earthquakes occurred along preexisting zones of weakness in Precambrian rocks. Wegweiser and others (1998) suggested that seismicity in northwestern Pennsylvania may be associated with the northwest-trending "cross-strike discontinuities" that are recognized in Paleozoic rocks and may represent reactivation of faults in the Precambrian basement. Using structure-contour maps constructed on the tops of lower Paleozoic strata, Alexandrowicz and Cole (1999) found evidence of preexisting northwest-striking faults in the epicentral region of the Pymatuning shock. The Harvard focal mechanism for the Pymatuning earthquake (a method used to infer the slip and orientation of the fault that generated an earthquake) indicates thrust faulting on a northwest-striking plane, which is consistent with the regional northeast-southwest compressive stress regime observed in the area. Seeber and Armbruster (1993) plotted three prior earthquakes in the epicentral area having magnitudes greater than 3; two were instrumentally located near the Pymatuning earthquake, and the third event occurred 20 to 30 km (12 to 19 mi) to the northeast in 1852 (Figure 1).

CHASING THE EARTHQUAKE WITH PORTABLE SEISMOGRAPHS. Within 24 hours of the main shock, field parties from three institutions—the Center for Earthquake Research and Information (CERI), University of Memphis; the Lamont-Doherty Earth Observatory (LDEO), Columbia University; and the U.S. Geological Survey (USGS), Golden, Colo.—arrived in the epicentral area to deploy portable digital seismographs to record aftershocks. Earthquakes are usually followed by aftershock sequences—the largest aftershock usually being a magnitude less than the main shock—and the number of aftershocks per day decays exponentially with time. In general, the sooner record-

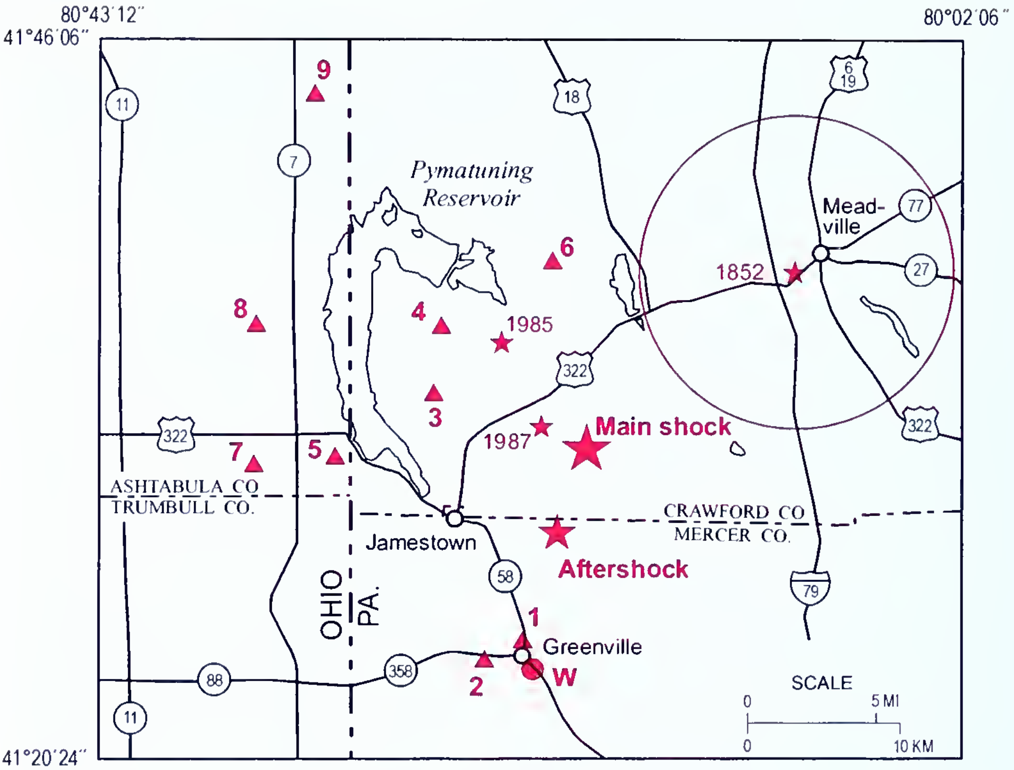

Figure 1. Map of the epicentral area showing the Pymatuning main shock and first aftershock as colored stars, large and medium, respectively; two prior instrumentally recorded earthquakes in 1985 and 1987 as small colored stars; and a historic earthquake in 1852 as a small colored star surrounded by a circle that illustrates the uncertainty of the location based on felt reports. Of the 12 portable seismographs deployed, the nine that recorded the first aftershock are shown as colored, numbered triangles (the corresponding seismograms are shown in Figure 2); the other three are omitted. The colored dot labeled "W" is USGS well Mr–1364. Latitudes and longitudes are approximate.

ing is begun, the greater the amount of information that can be obtained. Guided by the NEIC preliminary epicenter determination, the field party from CERI deployed its first seismograph at 2:00 a.m. Saturday morning. The LDEO field party began deploying seismographs on Saturday afternoon, and the USGS field party began deploying on Saturday evening. By Sunday, a total of 12 seismographs had been deployed, and we had set up a field headquarters at a motel near Greenville, Pa. (Figure 1).

Commonly, information about the causes of the main shock can be obtained from aftershock studies. Aftershocks that occur soon after the main shock tend to cluster near the fault plane that slipped during the main shock. Aftershocks too small to be detected by seismographs at regional distances can be recorded by a local seismograph array. These records are used to precisely locate the aftershocks, and particularly to determine their depths. The details of the location, orientation, and slip of the fault that caused the main shock can then be inferred from the pattern of aftershock locations. The nearest permanent seismograph station used in the NEIC location of the Pymatuning main shock was about 200 km (124 mi) away. The nearest seismograph that recorded the earthquake, approximately 50 km (31 mi) to the northeast, is operated by Brian Zimmerman of Edinboro University (who is also a member of the Public Seismic Network, found at <*http://psn.quake.net/*>), but the timing of this record is not sufficiently precise to be used in the earthquake-location determination.

The portable seismographs were generally deployed at the residences of private citizens, where electric power and security for the instruments were graciously provided. To minimize unwanted vibrations produced by the movements of daily life, the sensors were sited either within outbuildings or in backyards. With one exception, the seismographs stored recorded signals on disk drives and thus had to be visited to retrieve these data. The CERI group installed one of their seismographs at Thiel College in Greenville, where it was connected to the Internet and its data could be accessed remotely. We were thus able to use this station to monitor the local seismicity in near real time after the field parties departed the epicentral area on October 2, a week after arrival.

Unlike the 1986 northeastern Ohio earthquake that was followed by six aftershocks in the first 8 days (Nicholson and others, 1988), the first known Pymatuning aftershock was a magnitude 2.0 event that occurred on October 9 at 08:41 UTC (4:41 a.m. EDT), 2 weeks after the main shock. This aftershock has an epicenter of 41.477°N, 80.358°W (see Figure 1), a depth of 5.3 km (3.3 mi), and it was recorded at nine seismograph stations (Figure 2). There have been at least 10 additional aftershocks since the first aftershock, and they all have the same location within the uncertainties of hypocenter (focus) determination. The NEIC preliminary epicenter determination of the main shock was approximately 10 km (6 mi) west of the aftershocks, reflecting in part a mislocation due to the NEIC's calculation of the epicenter using global-average travel-time tables. The main-shock epicenter used in this report has been relocated by using travel-time tables that are appropriate for eastern North America; it is still about 5 km (3 mi) from the aftershock epicenters, a discrepancy that likely is partly due to error in the relocated main-shock epicenter resulting from lack of close-in observations. Some of the discrepancy between the epicenter of the main shock and those of the aftershocks may also be due

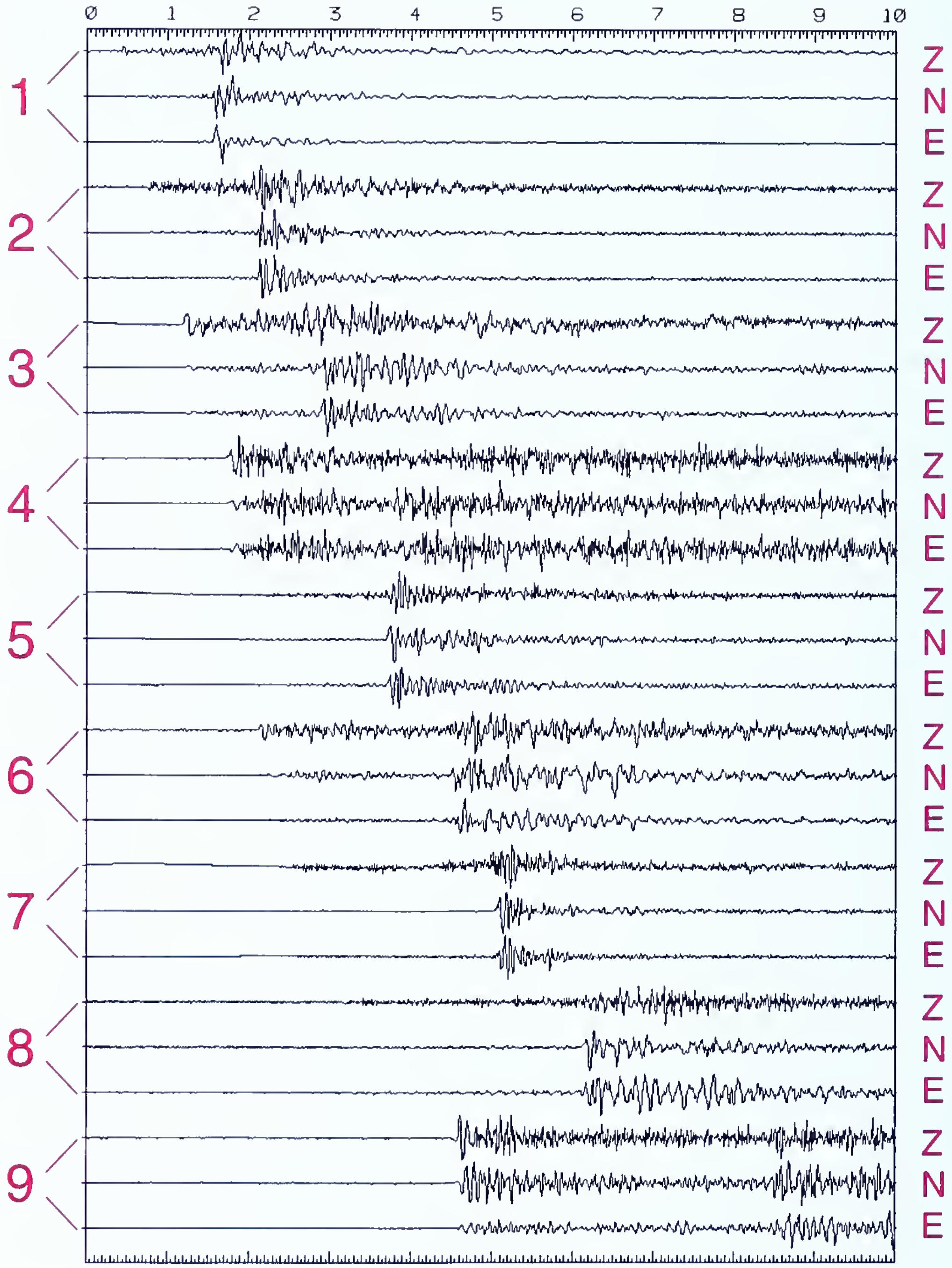

Figure 2. Seismograms of the October 9 aftershock recorded by nine seismograph stations (the locations of the stations are shown in Figure 1). Ten seconds of the three components of ground velocity recorded at each station are displayed (Z, up-down; N, north-south; E, east-west), and the stations are ordered from top to bottom according to their increasing distances from the epicenter. The amplitudes of each trace are scaled to the peak amplitude of that trace, and they cannot be compared from trace to trace. Note that there is a relatively weak primary arrival (the P wave) on the Z component, followed by a stronger secondary arrival (the S wave) on the horizontal components (N and E).

to the main-shock nucleation point occurring on a different part of the earthquake-causing rupture plane than the aftershocks, or to migration of the aftershock away from the main-shock source region with time, as is often observed in other main-shock/aftershock sequences.

Aftershock studies can also inform us about the effects of the main shock, that is, the intensities of ground shaking as indicated by damage to buildings and by human perceptions. Different sites exhibit variations of main-shock intensity that are often correlated with variations in the geologic characteristics of those sites. Similarly, aftershock records from those sites exhibit variations of amplitude and duration that can be used to corroborate the pattern of main-shock intensity and to investigate the mechanisms by which the corresponding geologic structures modify ground motions. Greenville and Jamestown, like other towns in the region, are built in valleys that are filled with as much as 100 m (328 ft) of glacial deposits.

An earthquake powerful enough to generate strong ground motions, unlike virtually any other natural or artificial phenomena, focuses the attention of the whole community almost instantaneously on the event. The World Wide Web, more than any other medium, allows members of that community to share the experience with each other. To inform people of the results of our investigation, and also—of equal importance—to solicit information about the earthquake from people who experienced it, we established a web site at our field headquarters. Our audience was the scientific community, the general public, and particularly the residents in the epicentral region who felt the earthquake or were aware of it from the local media coverage, because the residents could tell us their observations of the earthquake's effects.

INTENSITY OF THE EARTHQUAKE. An earthquake intensity is a number that represents the level of earthquake shaking in a community. The number is commonly represented as a Roman numeral, although on maps and in computer databases, Arabic numerals are used for conciseness and convenience. The intensity is assigned by consideration of the effects of the earthquake on people, on buildings and other human-made structures, on building contents, and on the landscape. The Modified Mercalli intensity scale is used in the United States to assign intensities, and it consists of descriptions of earthquake effects, ranging from I, "Not felt except by a very few under especially favorable circumstances," to XII, "Damage total." The maximum intensity of the Pymatuning earthquake was rated as VI, "Felt by all; many frightened and run outdoors. Persons made to move unsteadily. Broke [sic] dishes, glassware, in considerable quantity, also some windows. Fall of knickknacks, books, pictures. Overturned furniture in many instances. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight," for communities near the epicenter and for several additional communities in Pennsylvania and Ohio (Figure 3). Below are summaries of the intensity reports from two of those communities.

Greenville. A member of the Greenville Fire Department reported, "I was standing in a room on the second floor of my house when I felt the house shake violently for a short period of time. I heard a loud 'explosion-like' noise outside and some of my compact music disks fell off their storage shelf. I looked out the second floor window and saw all of my neighbors coming out of their homes. Most

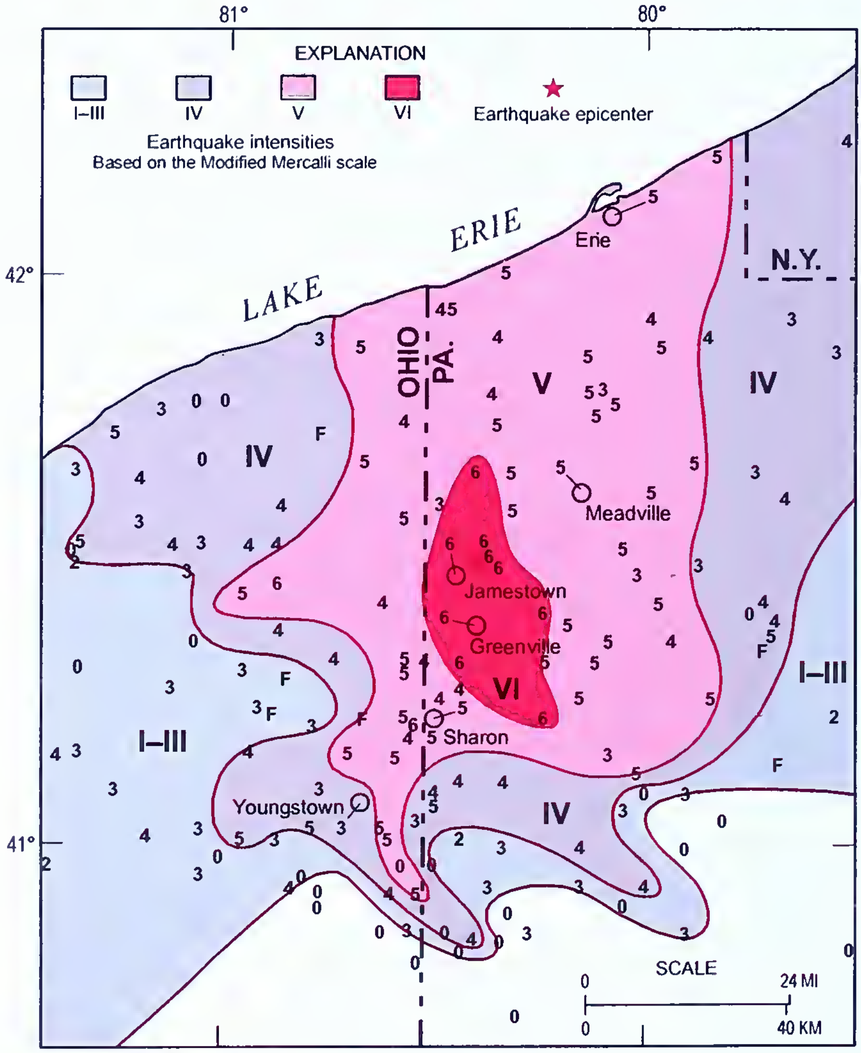

Figure 3. Large-scale map showing earthquake intensities in the epicentral area. Numbers indicate intensity at which earthquake was felt; 0, not felt; F, felt.

thought there was an explosion in the area. I drove to the fire station contemplating increased emergency activity due to whatever we had just experienced." The earthquake damaged a transformer at a factory, resulting in loss of power to the factory. A person was injured from being thrown to the ground. A few old chimneys cracked or lost bricks; exterior walls in some buildings sustained large cracks; some windows were cracked; in some houses, many items fell from shelves; items were shaken off store shelves; felt by all.

Jamestown. Ceiling tiles fell throughout the elementary school, and windows were broken in the building; an observer thought there would have been injuries in the school had the building been occupied at the time of the quake. Several old chimneys fell; concrete-block exterior walls sustained large cracks, and brick-veneer exterior walls sustained hairline cracks; interior walls sustained a few large cracks; plaster fell; many small objects overturned and fell; several dinnerware items and knickknacks broke; many items were shaken off store shelves; ten stores reported damage to inventory (see photograph on front cover); suspended objects swung violently; hanging pictures fell; many people ran out of buildings; felt by all.

Observations on damage and felt effects came from traditional sources used by the USGS for decades in its mapping of earthquake intensities and from submissions by electronic mail. The traditional sources of information are postal questionnaires, press reports, and reports from observers in the epicentral region. Geology students at Allegheny College in Meadville, Pa., conducted telephone and face-to-face interviews with people in selected communities affected by the earthquake and supplied approximately 100 survey reports.

The volume of e-mail observations far exceeded what had been collected previously for earthquakes occurring in the eastern United States. Overall, approximately 1,000 individual reports were submitted via the Internet. Most of these came from web sites at St. Louis University and the University of Memphis, and from e-mail collected at the Geological Survey of Canada. Some intensity observations were contributed by means of a form posted on a University of Nevada web site, and some observations were submitted to the USGS National Earthquake Information Center. Over 250 different communities are represented in the e-mail responses.

RESPONSE OF THE COMMUNITY. The Pymatuning earthquake caused much excitement in western Pennsylvania and eastern Ohio. Though this earthquake was relatively small (several events of this size happen each year in California), the fact that it occurred in an area that has very little seismic activity caused people to be very interested. Relative to other earthquakes of comparable size investigated by the USGS, the Pymatuning earthquake generated the most intense coverage by the local and regional media; for example, to do a story on the earthquake, a regional television station sent a news team in a helicopter that landed in the field behind our motel field headquarters. Even 2 months after the earthquake, stories relating to the aftereffects were still front-page news in the local media, and people were very interested in what results researchers found and were happy to complete intensity surveys.

The maximum Modified Mercalli intensity of VI assigned to the earthquake corresponds to minimal damage; however, any damage at all was a surprise to the residents. Few people in this area carry earthquake insurance (we have heard of only one person who actually had this insurance), and, therefore, any repairs were paid for entirely out-of-pocket. This became significant when water wells in the area began drying up within days of the event. As time has passed, there have been additional reports of new wells having to be dug, and a recent report of some wells in Ohio that have gone dry. The cost of most earthquakes is highly visible damage to buildings and other human-made structures, but the cost of the Pymatuning hydrologic effects is a hidden result of this earthquake.

HYDROLOGIC EFFECTS. Hydrologic changes related to the Pymatuning earthquake were reported by numerous residents of the Greenville-Jamestown area. The most serious change has been the loss of water at more than 100 household-supply wells not far from the earthquake epicenter. The maximum measured water-level decline was more than 30 m (100 ft). Other residents reported new flowing artesian wells, the formation of new springs, and changes in well-water quality ("black water and sulfur"). According to USGS hydrologists in Ohio, these hydrologic changes are nearly identical to those reported by nearby residents of northeastern Ohio after the earthquake there of similar magnitude in 1986.

Poth (1963) described shallow groundwater in the Mercer, Pa., 15-minute quadrangle (in southern Mercer County) as circulating in a series of "hydrologic islands." The dissection of the bedrock surface of the Mercer quadrangle has resulted in ridges largely surrounded by valleys containing perennial streams. These ridges constitute the hydrologic islands. Poth's description can be extended to northern Mercer County (see Figure 1). A shallow local groundwater-flow system operates within each hydrologic island and is hydrologically isolated from the local groundwater-flow systems in adjacent islands. Most recharge to these hydrologic islands discharges to the surrounding valleys; a small amount recharges to deeper flow systems.

The topographic ridge having the highest concentration of reported water-well changes is a textbook example of a hydrologic island. Most groundwater in this ridge is stored and transmitted via bedrock fractures and bedding-plane partings. Shallow wells on the highest points of the ridge went dry as soon as the morning after the earthquake. Deeper wells on the ridge and wells along the flanks of the ridges went dry in the weeks after the quake. Some of the first wells that went dry obtained good yields when deepened, but went dry again within a month.

Conversely, there were springs, wells, ponds, and streams that, either immediately after the earthquake or within several days, increased flow or began new discharges. These are all located on the lower slopes of the ridge and in the bordering stream valleys (the discharge areas). USGS observation well Mr–1364 in Greenville, located in a valley, recorded a 0.6-m (2-ft) rise in the groundwater level shortly after the earthquake (Figure 4). Some of the locations having increases in water level or flow returned to their pre-earthquake levels within two months, but most have not.

These hydrologic phenomena may be explained by the hypothesis that the earthquake created new fractures or opened old fractures through aquitards (low-permeability zones) beneath the upper aquifer(s). On the ridge-top recharge area, groundwater flow in the local flow system has a downward component. If the fractured-aquitard hypothesis is correct, the newly opened fractures increased the downward hydraulic conductivity through the aquitard, increasing the downward movement of groundwater. This would create a zone of water-table depression along the fracture(s). Shallow wells nearest the fracture(s) would have gone dry soon after the earthquake as the water table lowered. Later, as the water table continued to lower and the zone of depression spread, deeper wells on the ridge and wells along the flanks of the ridge would have started to go dry. Wells nearest the fracture(s) on the top of the ridge that went dry initially and were then deepened would have gone dry a second time as the water table continued to drop. A consequence of the increased downward movement of groundwater in the recharge area would have been an accompanying increase in discharge from new springs, flowing wells, and new wet areas (seeps) in the low-lying discharge area, and increased flow in the deeper flow systems as manifested by the

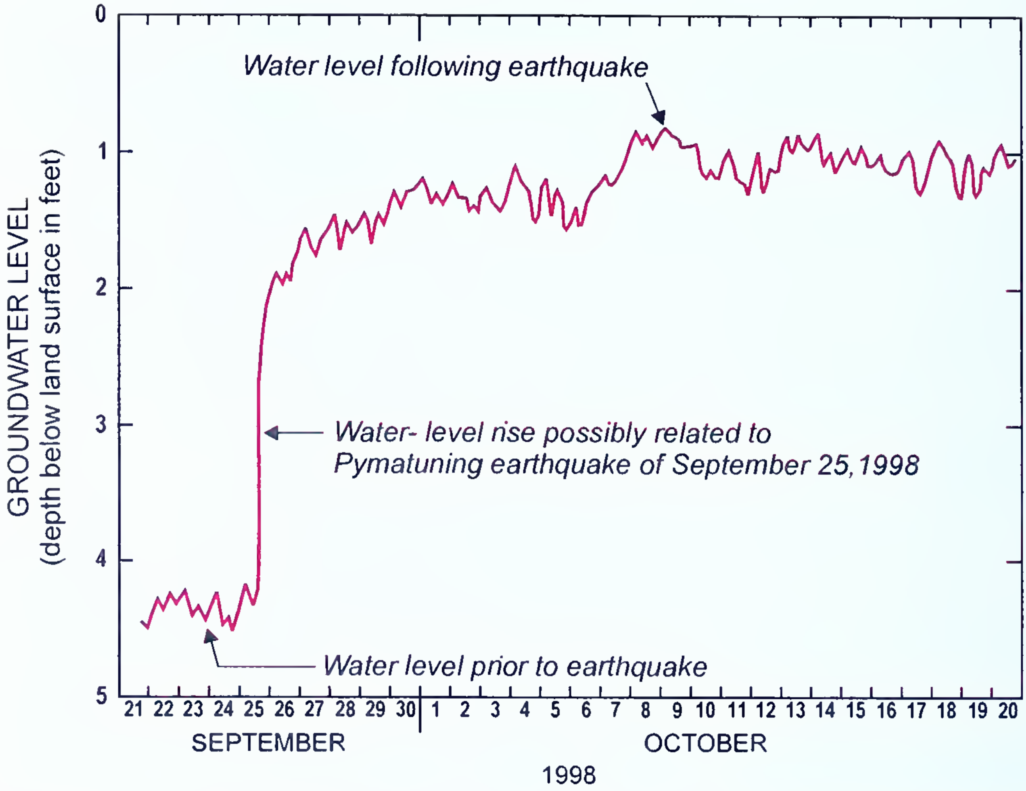

Figure 4. A 0.6-m (2-ft) rise in the groundwater level was recorded in USGS observation well Mr–1364 in Greenville on September 25.

water-level rise in Mr–1364 and by the presence of flowing wells in adjacent valleys. The local flow system does not yet appear to have reached a new equilibrium. These hydrologic changes currently are under investigation by the USGS in cooperation with the Pennsylvania Bureau of Topographic and Geologic Survey and Thiel College.

CONCLUSIONS. The Pymatuning earthquake jolted a community into an awareness of its relationship with the earth. The event may have been related to reactivation of "cross-strike discontinuities," whose presence is strongly manifested in the northwest-trending valleys that dissect the bedrock of the area. These valleys have historically been the loci of settlement, and today, as for most areas worldwide, the valleys contain higher population densities than the nearby ridges. The valleys are the sites of bounteous aquifers that supply the towns, but the valleys are also underlain by the greatest thickness of unconsolidated glacial deposits, which can amplify earthquake-generated ground motions that pose a hazard to the towns. Note in Figure 3 that the contours of earthquake intensity, that is, of increased shaking, exhibit a northwest trend. Conversely, the bedrock that underlies the less populated ridges between the valleys does not amplify the ground motions, but neither does it constitute a robust aquifer. The earthquake effects on the ridges were severe enough to damage the fragile aquifer, and many wells there went dry as a result. The fragility of the connection between the shallow aquifer and the deeper bedrock may perhaps be seen as a metaphor for our connection to Earth.

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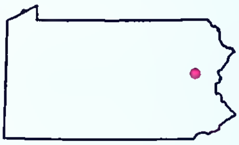
NEW RELEASES

Rocks and Ruins of the "Upper Grand"



A new open-file report on the geology and history of the Lehigh Gorge area has been released by the Bureau of Topographic and Geologic Survey. Open-File Report 98–03, **Rocks and Ruins of the "Upper Grand"—An Illustrated Trail Guide to the Geology and Historical Archeology of Lehigh Gorge State Park, Northeastern Pennsylvania,** was written by staff geologist Jon D. Inners.

The 62-page illustrated trail guide includes a road log and site descriptions of the geology and historical archeology of Lehigh Gorge State Park.

The "Upper Grand Section" of the Lehigh Canal contained 20 dams and 29 "high-lift" locks. It was in operation between 1829 and 1862. After abandonment of the canal, construction of railroads began. Now a rail trail through the Lehigh Gorge follows one of the former railroad grades.

"The gorge has a very rich canal and railroad history," said Inners. "I hope this report will help expose more people to the geology (rocks) and industrial archeology (ruins) of the Lehigh Gorge area."

Lehigh Gorge, located on the boundary between Carbon and

Lock no. 22 at Mud Run, one of the best-preserved locks of the "Upper Grand."

Luzerne Counties, exposes cliffs of red and gray sandstone that ranges in age from 375 to 320 million years old.

Six plates showing the bedrock geology, fold axes, glacial features, locks and dams of the "Upper Grand," railroads, and a map of the historical Lehigh Tannery are also included in the report.

Copies of Open-File Report 98–03 can be purchased for **$3.00 plus $0.18 sales tax** for Pennsylvania residents from Open-File Sales, Bureau of Topographic and Geologic Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania*. The report may be examined in the Bureau's library at 1500 North Third Street, Harrisburg, and in the Pittsburgh office of the Bureau at 500 Waterfront Drive.

Two New Groundwater Resource Reports Available

The Bureau of Topographic and Geologic Survey recently published **Water Resource Report 67, Groundwater Resources of Cambria County, Pennsylvania,** and **Water Resource Report 68, Hydrogeology and Groundwater Quality of the Glaciated Valleys of Bradford, Tioga, and Potter Counties, Pennsylvania.**

Water Resource Report 67, by staff geologist Thomas A. McElroy, consists of a 49-page text accompanied by a full-color, 1:50,000-scale geologic map of Cambria County showing the locations of selected wells and springs. The report includes descriptions of the water-bearing properties of 10 stratigraphic units, chemical analyses of groundwater from 5 springs and 70 wells, chemical analyses of 27 samples of acid mine drainage, hydrogeologic and well-construction data for 230 wells, and a comparison of the hydrologic cycle in a strip-mined and an unmined basin.

Water Resource Report 68 was a cooperative project between the Bureau of Topographic and Geologic Survey and the U.S. Geological Survey (USGS). It was written by John H. Williams of the USGS, Larry E. Taylor of Moody and Associates, Inc., and Dennis J. Low of the USGS. At the time the report was being prepared, Taylor was a geologist with the Bureau. The report consists of an 89-page text accompanied by a two-color, 1:100,000-scale surficial geologic map (on two plates) of the major glaciated valleys in Bradford, Tioga, and Potter Counties. The map shows locations of wells, test holes, and data-collection sites discussed in the text, and the locations of numerous hydrogeologic cross sections included in the margins of the plates. In the text, the authors describe the hydrogeologic setting and hydrogeochemical system in valleys north of the late Wisconsinan glacial border in north-central Pennsylvania. Hydrogeologic and well-construction data from approximately 900 wells and test holes are presented in tabular form in the back of the report. In their study, the authors supplemented these data with data obtained through geophysical surveys and well logs, groundwater-level monitoring, infiltration studies, and chemical analyses of groundwater from more than 200 selected wells.

The reports may be purchased from the State Book Store, 1825 Stanley Drive, Harrisburg, PA 17105–1365. Water Resource Report 67 is **$12.66 plus $0.76 state sales tax,** and Water Resource Report 68 is **$15.47 plus $0.93 state sales tax.** Sales tax applies to Pennsylvania residents only. All orders must be prepaid; please make checks payable to *Commonwealth of Pennsylvania*.

The geologic maps for both reports were printed before the books and were made available to the public at a reduced publication cost (see announcement in *Pennsylvania Geology,* v. 26, no. 3/4, p. 13). People who purchased these maps previously may obtain the accompanying books directly from the Bureau. If interested, send a check payable to *Commonwealth of Pennsylvania* for the balance in cost, **$4.46 (plus $0.27 state sales tax, if applicable)** for Water Resource Report 67, and **$5.87 (plus $0.35 state sales tax, if applicable)** for Water Resource Report 68, to the Pennsylvania Geological Survey, P. O. Box 8453, Harrisburg, PA 17105–8453.

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IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY
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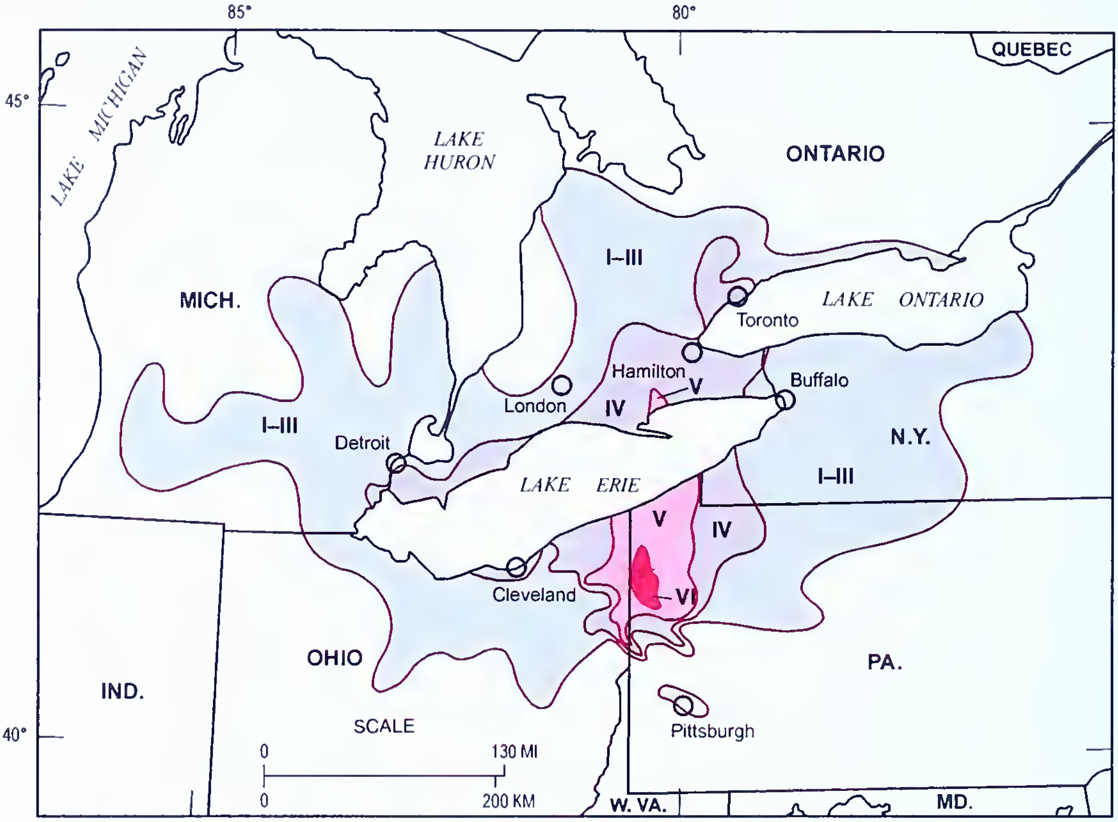
PYMATUNING EARTHQUAKE INTENSITIES

The map shows earthquake intensities throughout the region in which the Pymatuning earthquake of September 25, 1998, was generally felt. (See article on page 2.)



EXPLANATION

☐ I–III
☐ IV
☐ V
■ VI

Earthquake intensities
Based on the Modified Mercalli scale

★ Earthquake epicenter

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